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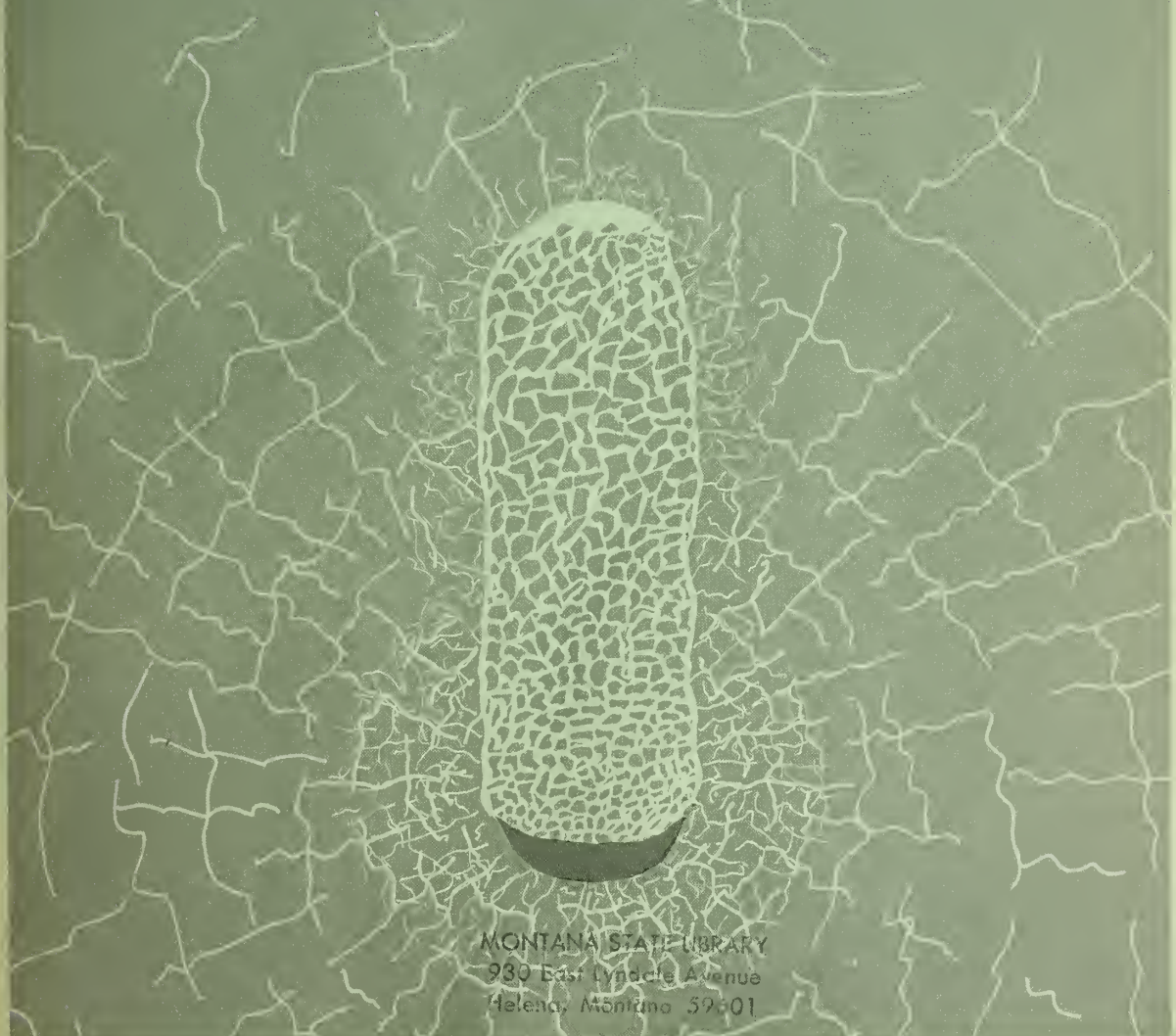
PLOWSHARE TECHNOLOGY ASSESSMENT

FINAL REPORT
IMPLICATIONS TO STATE GOVERNMENTS

Glenn A. Whan, Project Director



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IMPLICATIONS TO STATE GOVERNMENTS

September 1973

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ABSTRACT

This report summarizes the findings, conclusions, and recommendations of a study conducted by an interdisciplinary research team for the Western Interstate Nuclear Board (WINB) to provide information and guidelines to be used by the states of the Western Interstate Nuclear Compact in planning and decision making related to commercial Plowshare projects. The study centers on the safety and welfare implications associated with the use of underground, deeply buried, nuclear explosives in commercial applications.

This report has been written as a part of the Plowshare Technology Assessment Project of the Western Interstate Nuclear Board, supported in part by Grant No. GT-21 of the National Science Foundation.

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I. INTRODUCTION

Technology assessment, a method for systematically forecasting, identifying, and evaluating both beneficial and detrimental impacts of technology on society, is generally intended to be an input into some decision making process. Rapidly increasing activity among federal agencies in coordinative planning combined with greatly increased public interest and the resulting actions taken to control technology has brought about the requirement for a more systematic response from state governments on public issues. This makes technology assessment important to a state government because it provides a means of looking at interrelationships important to the welfare of its citizens. This technology assessment project was initiated by the Western Interstate Nuclear Board in recognition of these needs associated with the peaceful uses of nuclear explosives.

The Western Interstate Nuclear Board (WINB) is the operating arm of the Western Interstate Nuclear Compact, a legislative compact entered into by eleven of the member states of the Western Governor's Council (Alaska, Arizona, California, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) to provide a mechanism for cooperation in areas of mutual interest in the field of nuclear energy. Since its first meeting in September of 1969, the Board has been examining the problems in the nuclear field to determine the type of information which would aid state officials and legislators of the Compact states in their decision making.

The Atomic Energy act, passed by Congress in 1946 and amended in 1954, clearly indicated two main objectives of testing nuclear explosive systems: first, to maintain the nation's security and, second, to develop peaceful applications of nuclear explosives for the benefit of all mankind. Chemical explosives had been used for many years in the excavation of canals, in mining and quarrying, in stimulating the flow of petroleum, etc. In some applications, however, it appeared that nuclear explosives might have advantages over conventional explosives. Consequently, in 1957 the Atomic

Energy Commission established the "Plowshare"* program to develop peaceful uses of nuclear explosives.

Several of the western states served by WINB have extensive natural gas, oil shale, geothermal, and other resources which could eventually be employed in meeting the region's and nation's burgeoning energy and minerals requirements. Plowshare technology could possibly contribute to these needs by aiding the extraction of natural gas from deep, tight gas-bearing strata in some areas where recovery would not be economically feasible by conventional means. This study has not considered the conditions under which these resources could be recovered by means other than Plowshare technology; however, this work and other research and experiments indicate that at least a substantial portion of these natural resources may be economically recovered via Plowshare. Commercial application of Plowshare technology, however, offers a major challenge to planners and policy-makers in industry, in the scientific community, and in all levels of government. In response to this challenge a variety of social and environmental impacts as well as economic benefits must be evaluated.

In anticipation of further technological developments and emergence of considerable public debate as to benefits and costs associated with widespread commercialization, WINB initiated in 1971 the "WINB-NSF Plowshare Technology Assessment Project" as a means of developing a body of objective, independently-derived information and guidelines for use by states and other public policy organizations in planning and in decision making concerning commercial Plowshare projects. The intent of this study was not to decide whether or not various Plowshare projects within the western states should proceed but instead, in recognition of Plowshare as a pervasive technology, to provide state and local bodies with information which will serve as a basis for making safety and welfare decisions.

Funded by WINB and the National Science Foundation, the project involved the participation of a broadly-representative steering committee, an interdisciplinary research team of senior faculty members, and

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*Isaiah 2:4: "... and they shall beat their swords into plowshares."

several groups of graduate student assistants at the Universities of Colorado, New Mexico, Utah, and Wyoming, and at Colorado State University. Beyond its primary objective of providing guidelines and recommendations for state-level decision-making, it is hoped that this study will stimulate other technology assessment studies by regional academic institutions and government agencies.

Four major areas were studied: (1) assessment of Plowshare applications and their potential roles in optimum utilization of energy and material resources consistent with environmental conservation and other concerns, (2) evaluations of possible release of radioactivity, seismic effects, and other hazards, to assure protection of citizens and natural resources, (3) studies of legal considerations, embracing current and desirable new federal and state laws and policies, to assure intergovernmental cooperation and public involvement in planning and regulatory processes, and (4) assessment of methods for encouraging public participation in benefit-cost analysis of projects which might have significant impact on society.

Since Congressman Daddario first used the term technology assessment to describe the systematic evaluation of the impact of new or developing technologies and their potential applications,[1] there has been considerable study and discussion on how to conduct and how best to utilize technology assessment. The recent literature describes in detail the broad range of complex questions to be addressed and the methodology to be applied in making comprehensive technology assessments.[2-7] However, there is no generally accepted method for conducting the comprehensive analysis required. Nevertheless, it is clearly recognized by the research team of this project that only a few aspects of the four major areas pointed out above have been researched in depth. Many other aspects have been identified for future and more comprehensive assessment not in keeping with the limitations on time and resources associated with this study. For instance, a particular Plowshare project at a specified location would have to be identified before a more detailed analysis could be undertaken. Moreover, in this study no effort could be made to analyze second and higher order environmental impacts or alternative methods to Plowshare.

It is important to emphasize that this study is an assessment of underground, deeply buried, completely contained, nuclear-explosion technology (those of greatest interest for commercial industrial applications) and not of shallow-buried excavation applications of nuclear explosives. In recent years, the USAEC has concentrated its industrial Plowshare development program in the area of natural gas stimulation. Experience to date is based on the three AEC-sponsored experiments (Project Gasbuggy, Project Rulison, and Project Rio Blanco) conducted in cooperation with several private industries and on the extensive nuclear weapons testing program. Considerable knowledge of ground motion effects, radiation effects, and other phenomena associated with underground nuclear detonations has been accumulated, but not all of the available information can be extrapolated appropriately to commercial Plowshare operations. Because of the abundant data available on natural gas stimulation relative to other proposed uses of Plowshare technology and again the limited time and resources for primary research, gas stimulation has been given by far the most attention. Although an attempt has been made to reach conclusions and make recommendations generally applicable to a wide variety of Plowshare applications, some of these might not universally apply.

The Project Steering Committee and Principal Investigators initially held a meeting to define and rank the important issues. Technical data on these issues were then gathered by students and faculty from available AEC and industrial reports as well as from various professional journals. In some cases, few data were available and independent research and analysis were required. A number of individuals in national laboratories, government agencies, and industry were contacted personally for information. The Project Steering Committee and Principal Investigators subsequently held a meeting every three months to discuss the results of analyses of issues and to plan the future direction of work.

Twelve research reports, covering a wide variety of subjects in the four major areas, are used as the information base for this final report. As a sounding board, at least eight of these papers have been presented at professional meetings. This final report summarizes the most important findings, conclusions, and recommendations for this study representing a group concensus by the Steering Committee and the Principal Investigators.

II. CONCLUSIONS AND RECOMMENDATIONS

The principal conclusions and recommendations concerning the potential use of industrial Plowshare applications in the Western Interstate Nuclear Compact states are summarized below. The primary emphasis is to provide state and local bodies with a basis for making safety and welfare decisions.

Assessment of Needs

Of the possible needs that might be served by industry with nuclear explosives, the most immediate and extensive appears to be the stimulation of deep tight natural gas formations. A natural gas production program which would recover 65 trillion standard cubic feet of gas from 2000 wells in Wyoming and Colorado over a twenty-three year construction period has been studied. The annual production rate of this nuclear stimulated gas would be about 2.5 trillion standard cubic feet in 1990, which would represent about 6% of the U.S. projected annual demand for natural gas. Success in natural gas stimulation and public acceptance of that program can provide a stimulus to the continued development of an industrial Plowshare program.

The other needs that might be served with nuclear explosives do not appear to be as urgent, e.g., geothermal stimulation, cavities for gas storage, radioactive waste disposal, in-situ leaching of copper, and in-situ extraction of oil shale. Although one or more of these applications may eventually prove to be the most beneficial, they are still under study and can thus profit from the actual experience gained in natural gas production.

Because of classification restrictions on detailed information about nuclear devices, it cannot be demonstrated by this project team that a net energy gain would accrue from the use of one energy source (fissionable material) to obtain another energy source (natural gas). AEC scientists have studied this energy trade off, however, and have assured that the use of fissionable material for gas stimulation versus its use in nuclear power reactors is in the nation's overall best interest in terms of energy resource utilization.

Limitations on the supply of special nuclear material for nuclear explosives may well prohibit a rapid commitment to natural gas stimulation in spite of the demonstrated need. The requirements for uranium-235 or plutonium-239 for natural gas stimulation could be as much as 5% to 10% of the requirements for the nation's concurrent nuclear power program.

Environmental Impact

Because the use of nuclear explosives in industrial applications involves potential risks to the public and insults to the environment, all reasonable safeguards must be employed to protect public health and property and to minimize disturbances that may upset the ecology of the region. The environmental impact report prepared by the industrial sponsor in compliance with the National Environmental Policy Act should cover the environmental impact on the entire area of proposed development for a Plowshare project and the disposition of the depleted site.

No evidence indicates that a Plowshare detonation will prematurely trigger a major earthquake that is near the point of natural occurrence. Associated aftershocks and strain release events are of such small magnitude that they will not increase the seismic hazards associated with an industrial project. Seismic damage will be mostly limited to the man-made environment in close proximity to the explosion site, particularly building damage, but public inconvenience must also be considered. Based on many underground nuclear experiments, reliable methods have been developed for predicting the effects of seismic waves including the expected ground motions and the degree of expected structural damage. Some damage is certain to be caused by any Plowshare detonation, and adequate procedures must be established to determine accurately the extent of such damage. All possible care must be taken to minimize architectural damage by predetonation preventive maintenance and bracing. The natural seismic activity in the region of a proposed Plowshare project should be well established before detonation. Seismic monitoring must thus be required both before and after each Plowshare detonation.

Seismic effects from underground nuclear explosives will be the limiting factor on the explosive yield for industrial applications. Explosive

yields for industrial applications in the western United States might well be limited to one-hundred kilotons per single detonation until additional experience has been obtained regarding building damage and other environmental impacts.

The technology of nuclear explosives is well understood by the technical community, and the type and quantity of radioactive material produced by a typical explosive is well-known. Shielding techniques have been developed which can reduce the amount of neutron activation products to a minimum in the surrounding geological formation.

At the time of detonation, prompt or dynamic venting of radioactivity, because of the usual depth of nuclear device burial, is unlikely in industrial Plowshare projects. Of greater probability will be seepage of radioactive materials through man-made intrusions in the containment structure and through the surrounding geological formation.

To minimize the possibility of leakage of radioactivity to the atmosphere, minimum depths of burial of nuclear explosives for industrial Plowshare operations should be established. On the basis of experience with underground testing at the Nevada Test Site, it is recommended that the minimum depth of burial for Plowshare detonations be, conservatively, twice the minimum required at NTS.

The most serious pathway of radioactivity to the populace appears to be via groundwater. Again, because of the depth of typical Plowshare detonations, the bottom of the lowest aquifer region containing mobile water is generally thousands of feet above the detonation induced rock fractures. In most cases where groundwater contamination might occur, many years would be required for water to move away from the contaminated explosion zone because of the extremely low flow rates commonly found in subterranean groundwater systems.

During the planning stage of an industrial Plowshare project, a thorough natural background radiation survey of the proposed area and its surroundings must be conducted. A network of monitoring stations for air, soil, water, vegetation, and milk must be set up. This background survey should continue through all four seasons. At the time of the nuclear

detonation and for some period afterwards, a surveillance program must maintain a continuous assessment of radioactivity levels. Atmospheric and groundwater monitoring must be carried out both before and after each Plowshare detonation at sufficient locations and for durations long enough to demonstrate definitely that neither venting or seepage into the atmosphere nor radioactive contamination of ground water occur. If this surveillance indicates that a significant release of radioactivity has occurred, planned control measures must be undertaken immediately to protect the general public.

Studies of the potential radiation dose commitments postulated for normal Plowshare operations indicate that there is no justification in expecting either observable acute or chronic effects of radiation on the human or plant and animal populations which will be at risk. In the case of accidental venting or seepage, planned control measures must protect human populations. Only minor effects would be expected for the local animal populations, although again planned control measures must protect against potential food chain contamination.

Impact on Local Communities

Public perception of the impact of a Plowshare project on a local community may be different from that of an industrial sponsor; therefore, the prospective economic gains as well as the greater social burdens in a particular community must be studied in advance and clearly presented to the local community. Industrial Plowshare applications do not appear to be employment intensive industries for long periods of time. Anticipated economic gains to local communities in terms of increased employment, income, and tax revenues must be large enough to justify the potential costs to the population most vulnerable to Plowshare risks.

Legal Aspects

The presence of unresolved constitutional questions makes the task of deciding upon wise Plowshare policies for the states exceedingly difficult. Furthermore, until at least some of the constitutional questions are resolved, the task of designing badly needed state legislation to deal with Plowshare problems is practically impossible. Consequently, it seems of

paramount importance that judicial tests of the critical issue of state versus federal power be deliberately undertaken without further delay.

The federal government's control of special nuclear material dictates that industrial Plowshare technology cannot advance any faster or further than federal policy permits. It does not follow, however, that the states should not have the power to constrain the rate or conditions of that technology's application within their respective boundaries. The state power over Plowshare projects is particularly uncertain when dealing with federal lands. State policies should be formulated on the assumption that an independent state regulatory power over industrial Plowshare including the right to review, to veto, to issue or deny permits, and to set up more stringent safety standards is valid.

The Possible State Roles

It appears ill-advised at this time for states to enact moratoriums on Plowshare projects via statutes or referendums. Instead, it is suggested that statutes and administrative regulations provide for adequate resources and procedures for evaluating Plowshare projects and programs on their individual merits.

The National Environmental Policy Act requires that an assessment of public benefits to be derived and alternative means for achieving the same industrial goals be taken into account in any commercial Plowshare decision by the AEC. There is no reason, however, why any state should be precluded from making its own assessment independently of the AEC. Thus, a definite state role is the evaluation of benefits and costs to the state from industrial Plowshare projects.

Another role that state governments must accept involves review of project procedures for eliminating or minimizing damaging seismic motion and radioactive venting at the time of detonation as well as later radioactive leakage or seepage which might lead to ground water contamination. This role also involves the establishment of standards of acceptable levels of radioactive contamination in the products as well as approval of acceptably safe methods for disposing of radioactive byproducts. The states may wish to assure such roles by advocating these provisions in new federal legislation authorizing the commercial phase of Plowshare.

A state which chooses to establish its own radioactive contamination standards for Plowshare activities should also establish its own inspection and enforcement programs. Although some states may not set up their own monitoring programs, they must be involved in approving such monitoring programs and in passing independent judgment on the results obtained. At a minimum, it is recommended that states establish procedures to assure that groundwater and the atmosphere in the vicinity of an industrial Plowshare project are both adequately monitored and that they do not contain unacceptable concentrations of radioactivity.

It is recommended that existing state statutes concerning radiation control, radiological health, air and water pollution, and natural resources be reviewed as to their adequacy in regulating Plowshare projects. Those states which have not assumed from the AEC responsibility for regulating certain radioactive materials as provided for in Section 274 of the Atomic Energy Act ("Agreement state" program) should consider implementing by statute or agreement this program to provide a basis for at least a portion of the state's regulatory efforts concerning Plowshare activities.

Even though safeguards are exercised in industrial Plowshare activities, the risk of damage to health and property remains. Uniformity among the several states in procedures for treating Plowshare damage claims may be desirable, although federal power may supersede the tort rules of the states. The inadequacies and uncertainties of ordinary tort law for dealing with possible Plowshare-caused injuries and damage demand legislative attention. States must establish procedures to assure that local citizens receive adequate compensation for actual physical damage as well as for the nuisance and inconvenience of seismic effects.

The federal government provides indemnification with respect to nuclear reactors under the Price-Anderson provisions of the Atomic Energy Act. However, for several reasons, it is highly doubtful that the Price-Anderson provisions provide adequate protection (or even any protection at all) in the Plowshare context, even as modified by the most recent Hosmer Bill. Thus, any state in which commercial Plowshare activity is planned would be well advised to assure that adequate financial capacity exists to satisfy valid damage claims before permitting the project to

proceed. This would probably involve compulsory insurance and government indemnity to underwrite potentially disastrous losses.

In addition to general provisions for compensation, states should review their workmen's compensation laws to assure adequate and prompt indemnity of work injuries in Plowshare projects, particularly from cummulative low-level radiation exposures. Lack of effective procedures of early discovery, proof, and compensation for such industrial hazards would place the financial consequences entirely on the state.

State Institutional Implications

While specialized competence in fields relevant to Plowshare technology may exist in certain state agencies, the ultimate decision power in state Plowshare policy should not be placed in any single agency's hands. The ultimate responsibility for Plowshare policy is best placed with the governor of the state who is politically accountable and who can draw upon any technical expertise that he may find available within or outside of his state's administrative machinery.

Public Participation

A well-informed public is a prerequisite for constructive public participation in the state's decision-making process for Plowshare projects. The public must be given all facts which bear relevance to a specific Plowshare project, and they must be made aware of the social and economic benefits, possible risks, and public and environmental protection measures. For this purpose, public hearings, public meetings, opinion polls, public referendums, legislative procedures, and Governors' advisory committees can be used.

Benefit-Cost Considerations

Benefit-cost calculus is still in its very early stages of development. In the absence of reliable quantitative models of benefit-cost analysis, informed judgement based on available costs and benefits information must play the major role in decision making for an industrial Plowshare project. These decisions should be made at the state level by officials who are capable of examining the necessary factors thoroughly and objectively but who can also be held politically responsible for their decisions.

III. PLOWSHARE STATE OF THE ART*

Chemical explosives have been used for many years for peaceful purposes in mining, excavation, and oil and gas well stimulation. Nuclear explosives, however, contain much more energy or explosive power in a much smaller volume and can therefore be more easily transported and emplaced underground. The "yield" of a nuclear explosive is specified in terms of the quantity (thousands of tons: kilotons, or millions of tons: megatons) of TNT that would release the same amount of explosive energy. Thus, a nuclear explosive equivalent to 100 kilotons of TNT (a volume roughly the size of a twenty-story building) can be contained in a cylinder about one foot in diameter and fifteen feet long.

Two types of nuclear explosives are currently in use in Plowshare projects: fission and fusion. In fission the nuclei of uranium or plutonium atoms split into two smaller atoms; "nuclear energy" is simultaneously released. Fusion occurs when the nuclei of the heavy isotopes of hydrogen combine to form an atom of helium, thereby releasing nuclear energy. A nuclear explosion is thus the result of billions upon billions of atoms either fissioning or fusing in less than one second. For equal weights of materials, fusion reactions between the isotopes of hydrogen can liberate three or four times as much energy as in the fission of uranium-235 or plutonium-239. The fission explosive has some advantages for use in hydrocarbon stimulation projects (less radioactive contamination of the product); however, the fusion explosive's greater power and relatively lower cost make it attractive for some other Plowshare applications.

Uranium-235 and plutonium-239 are the materials used for fission explosives. Natural uranium is 99.3% U-238 and only 0.7% U-235. The U-235 must therefore be separated from the more abundant isotope by the gaseous diffusion process. Plutonium-239 does not occur in nature but instead must be made by the absorption of neutrons (transmutation) in uranium-238 in a nuclear reactor. Hydrogen-2 (deuterium) and hydrogen-3 (tritium are the materials used for fusion explosives. Deuterium is plentiful in all

*Although specific reference are not indicated in this section, a list of additional background reading is suggested in Section XIII.

water in nature; for roughly every 6500 atoms of ordinary hydrogen in water, there is one atom of deuterium. The deuterium is easily separated from ordinary hydrogen by distillation and electrolysis. Tritium on the other hand is not plentiful in nature and must be produced by neutron transmutation of lithium.

When a nuclear explosive is detonated underground, large amounts of energy are liberated in less than a second in the form of heat. The resulting high temperatures vaporize the rock immediately surrounding the explosive and create a spherical cavity containing hot gases at high pressure. These gases expand the cavity and either break through the ground surface (excavation) or stop when the surrounding rock is strong enough to resist further expansion (completely contained). In completely contained nuclear explosions in rock, except those in salt formations, this cavity then collapses leaving a "chimney" of broken rock.

The peaceful uses of nuclear explosives can be grouped into three principal categories: underground engineering, excavation, and scientific research. Underground engineering applications utilize the effects of completely contained nuclear explosions, excavation applications utilize the cratering effects of less deeply buried nuclear explosions, and scientific applications make use of the high density of neutrons produced by the explosion. In the early years of the Plowshare program, almost all of the effort was directed toward basic research on the phenomena associated with nuclear explosives. Gnome, the first Plowshare nuclear explosive phenomena experiment , was conducted in December 1961, and Sedan, the first Plowshare nuclear cratering experiment, was conducted in July 1962. In these and other experiments, data were obtained on radioactivity, air blast, and seismic effects; on cavity-chimney growth and collapse; on chimney size and dimensions; and on the extent of fracturing. In recent years, the principal emphasis in the Plowshare program has shifted from excavation to industrial applications. That is the application toward which this technology assessment project has focused. A brief chronology of the Plowshare program, particularly as it related to underground industrial applications, is presented in Appendix A.

Following a completely contained underground nuclear explosion, the chimney produced is surrounded by a large volume of partially fractured rock which now has a high increased permeability for fluid transport. The void volume and increased rock surface area resulting from the chimney and associated fractures provide the basis for underground engineering applications. Figure III-1 shows the chimney and fractured rock zone produced by the contained detonation of a single nuclear explosive in solid rock. Several configurations for multishot arrays can enhance fracturing, e.g., two or more explosives positioned at different elevations in a single drill hole (see Figure III-2). Another configuration, the close-packed array, attempts to maximize rock fracture by placing the explosives in a close-packed array so that the shock waves will combine to produce a maximum fracturing effect (see Figure III-3).

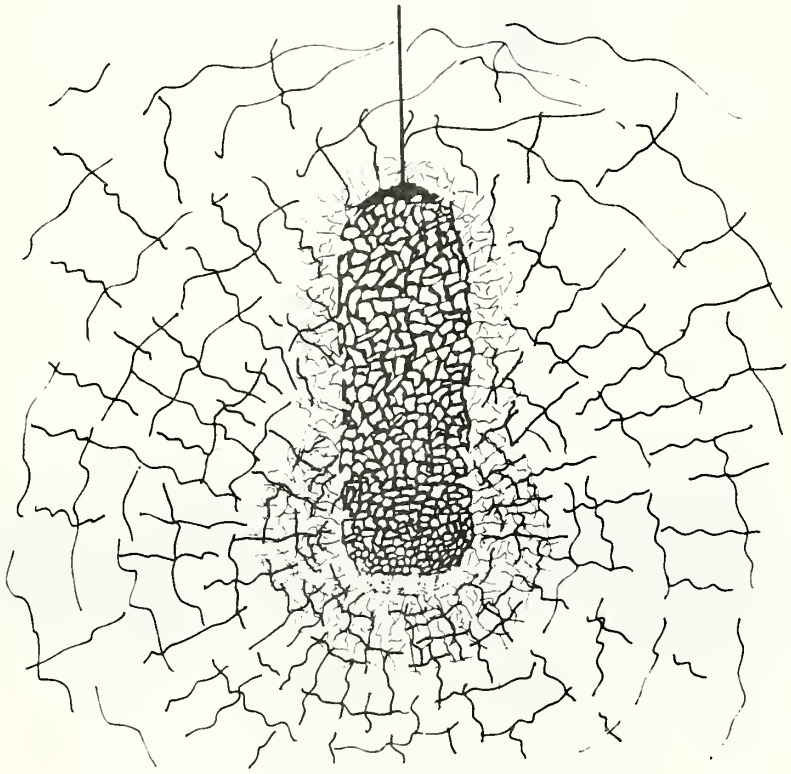


Figure III-1. The chimney and fractured rock zone produced by the contained detonation of a single nuclear explosive in solid rock.

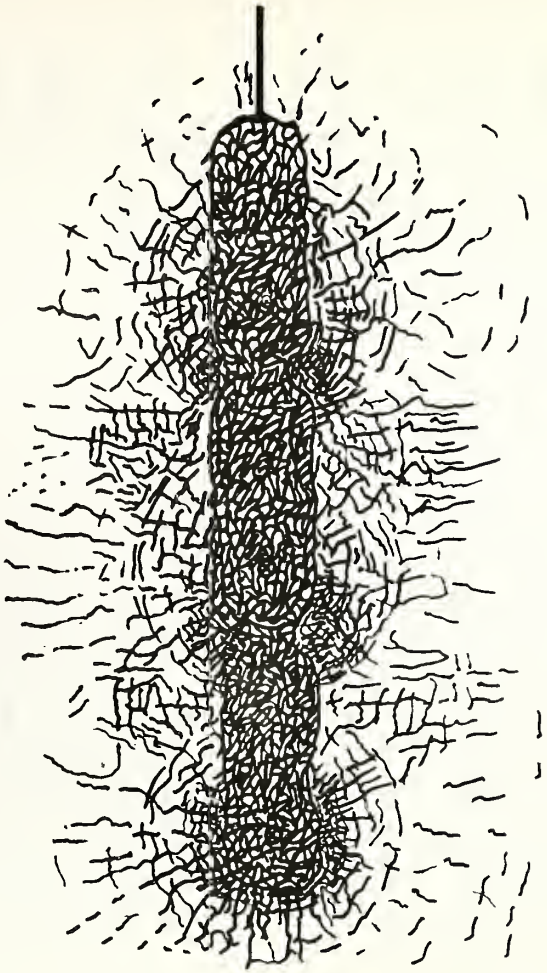


Figure III-2. Multiple Explosives at different elevations in a single drill hole.

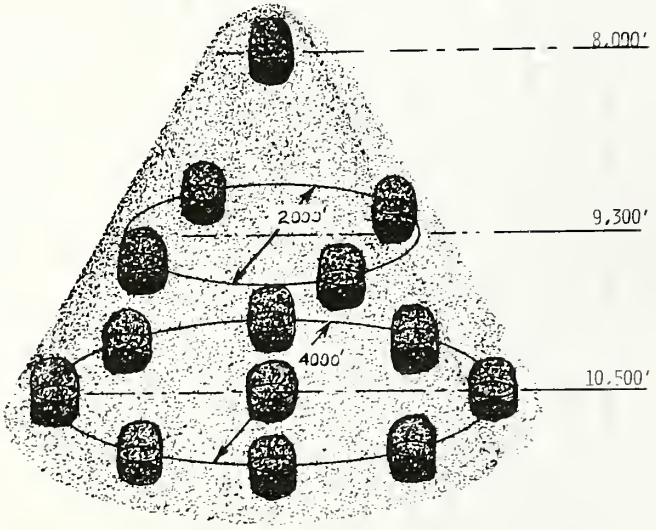


Figure III-3. Multiple explosives in a close-packed array.

Although it is far from being an exact science, the size of cavities formed by underground explosions can be predicted with reasonable accuracy. The yield of the explosive, the depth of burial, the type of medium, the water content, and the presence or absence of pre-existing faults and fractures are the main factors which determine the size of the chimney and the total volume of fractured rock produced. The yield of the explosive, however, is the predominant factor in determining this volume. Table III-1 demonstrates the cavity size in relation to the yield of the explosives and the depth of burial in sandstone.

In that the principal interest at the present time is the stimulation of tight natural gas reservoirs, emphasis is being given by the AEC to providing an explosive with characteristics suited to that purpose. The Diamond device, a small diameter explosive which will result in minimal radioactivity in the natural gas, will withstand the severe temperature and pressure environment of deep gas reservoirs, and can be made at a minimum cost, is under development. Table III-2 shows a comparison of the nuclear explosives used to date with those projected for future gas stimulation projects.

The United States Atomic Energy Commission has released projected charges for nuclear explosives. While these charges were developed primarily for excavation projects, the manufacturing costs of these explosives and those projected for Plowshare applications are close enough to use in the economic studies of the underground engineering applications. The projected costs range from $350,000 for a nuclear explosive with 10 kilotons yield to $600,000 for a nuclear explosive with two megatons yield. These charges cover nuclear materials, fabrication and assembly, and arming and firing services.

The economics of an industrial Plowshare project will of course depend greatly on the specific application. Many other expenses are associated with the nuclear detonation in addition to the AEC charge for the nuclear device: the safety program, site preparation, drilling an emplacement hole, and explosive emplacement and stemming. Estimated costs per well for commercial gas stimulation range from about 2.5 million dollars in the Colorado Piceance Basin (three 100-kiloton explosives per well)

Table III-1

Approximation of Cavity and Rock Failure Radii From Simple Scaling Rules

Yield Kt.	Explosion Depth 2,000 ft.		Explosion Depth 5000 ft.		Explosion Depth 10,000 ft.		Explosion Depth 15,000 ft.	
	Cavity Radius	Failure Radius	Cavity Radius	Failure Radius	Cavity Radius	Failure Radius	Cavity Radius	Failure Radius
10	75 ft.	375 ft.	59 ft.	265 ft.	50 ft.	185 ft.	45 ft.	135 ft.
25	101 ft.	505 ft.	80 ft.	360 ft.	68 ft.	252 ft.	61 ft.	183 ft.
50	127 ft.	635 ft.	101 ft.	455 ft.	85 ft.	315 ft.	77 ft.	231 ft.
100	161 ft.	805 ft.	128 ft.	576 ft.	107 ft.	396 ft.	97 ft.	291 ft.

Source: Report of the Committee of Industrial Plowshare Applications Economics of Stimulating Natural Gas Reservoirs with Nuclear Explosives, Atomic Industrial Forum, Inc. (November 1970).

Table III-2

Comparison of Nuclear Stimulation Explosives

EVENT	GASBUGGY	RUILSON	RIO BLANCO*	WAGON WHEEL*
DATE	December 1967	September 1969	May 1973	1975 (?)
PURPOSE	Gas Stimulation Experiment	Gas Stimulation Experiment	Gas Stimulation Experiment	Gas Stimulation Experiment
AEC SPONSOR	LRL	LASL	LRL	LRL
TYPE	Ex-Military Fusion	Ex-Military Fission	Diamond Device	Diamond Device
PLACE	Near Farmington, N.M.	Near Rifle, Colorado	Near Meeker, Colorado	Near Boulder, Wyoming
YIELD	29 ±3 kt	40 ±8 kt	3 each, 30 kt	5 each, 100 kt
FIRING MODE	Singly	Singly	Simultaneously	Sequentially
DIAMETER & LENGTH	17 inches 13 feet	9 inches 15 feet	7.8 inches 16 feet	7.8 inches 16 feet
ENVIRONMENTAL SHIELDING	Yes	No	Yes	Yes
NEUTRON SHIELDING	No	Yes	Yes	Yes
PREDICTED RADIOACTIVITY PRODUCED	40,000 Ci H-3 350 ±20 Ci Kr-85 0.4 Ci Ar-39 7.5 Ci C-14	10,000 Ci H-3 1,064 Ci Kr-85 Traces of Hg-203	3,000 Ci H-3 2,070 Ci Kr-85 Less than 7.5 Ci C-14	10,000 Ci H-3 11,500 Ci Kr-85 Less than 7.5 Ci C-14

*Data from Pre-shot Publications.

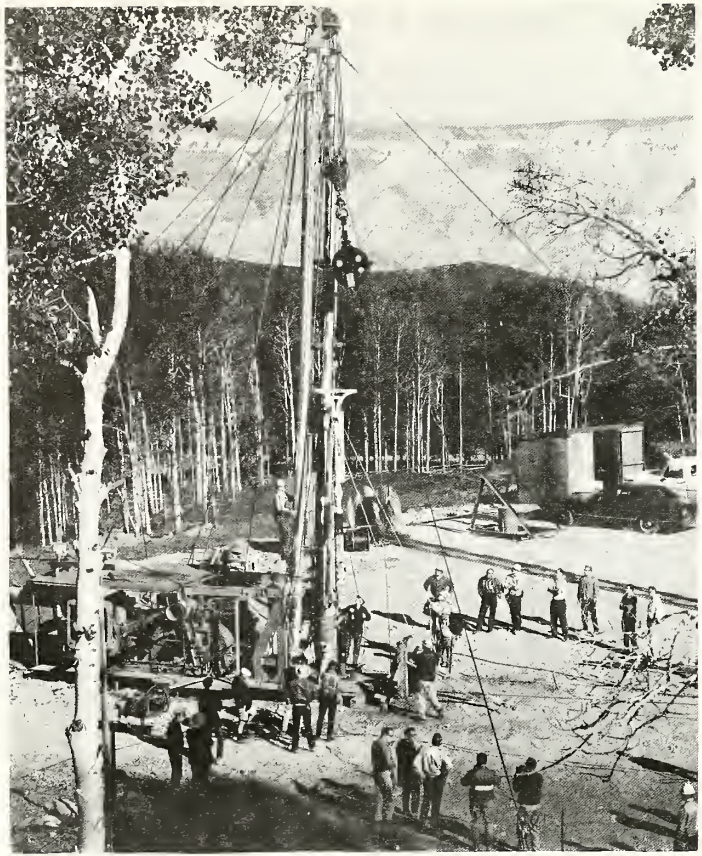


Figure III-4. Rulison device being lowered into emplacement hole, western Colorado, September 1969.

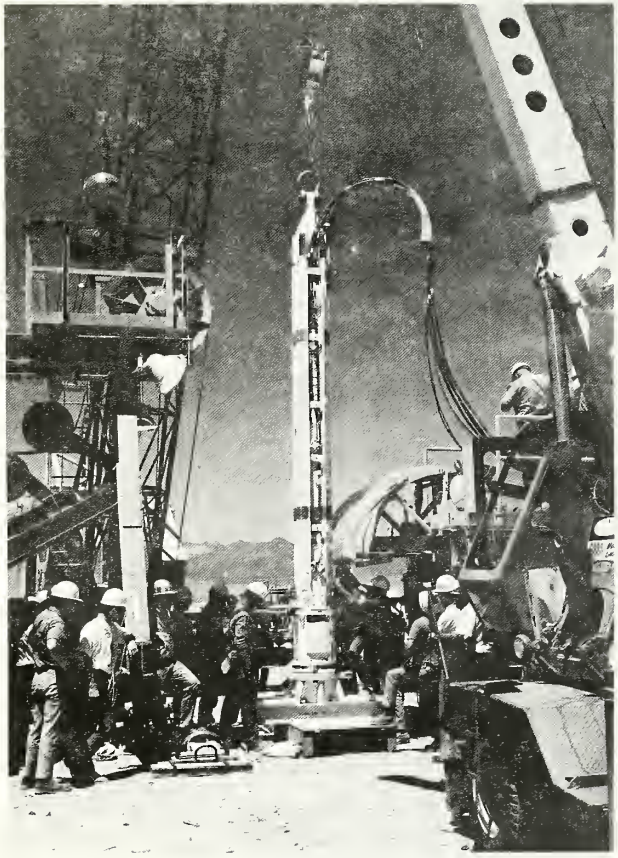


Figure III-5. Diamond device being lowered into emplacement hole, "Miniata" Device Development Project, Nevada Test Site, July 1971.

to 4 million dollars in the Wyoming Green River Basin (five 100-kiloton explosives per well).

At this time, the industrial Plowshare technology has developed to the stage where several companies have submitted proposals for joint government-industry experiments to investigate the feasibility of several concepts for specific applications of nuclear explosions (see Appendix A). The first joint government-industry underground engineering explosion was the Gasbuggy experiment conducted on December 10, 1967, by the AEC and the El Paso Natural Gas Company. A 29 kiloton nuclear device was detonated at a depth of 4240 feet, 55 miles east of Farmington, New Mexico. Gasbuggy was designed to develop the concept of nuclear stimulation of natural gas from formations of low permeability. Production tests of the chimney well have since resulted in a cumulative production of 295 million cubic feet of hydrocarbons and in potential gas recovery over a 20-year period estimated at 900 million cubic feet. This would be an increase by a factor of at least 5 over estimated recovery from conventional field wells in this low permeability area.

The second underground engineering nuclear explosion, Project Rulison also a gas stimulation experiment, was conducted on September 10, 1969. Participating in this project with the AEC were the Austral Oil Company and CER Geonuclear Company. A 40-kiloton nuclear device was detonated at a depth of 8425 feet, 15 miles southwest of Rifle, Colorado. The total gas production from this experiment has been 455 million cubic feet, and the estimated potential gas recovery over a 30-year period is about 6 billion cubic feet (the average potential production of nearby conventional wells is 260 million cubic feet).

Projects Gasbuggy and Rulison both seem to have been successful in their experimental goals. In each event, it was confirmed that effective communication between the gas bearing formation and the explosion produced rubble chimney had been established. Computational models were fitted to the observed formation and chimney properties, and long-term results were predicted which were at least partially substantiated by the production testing.

The next step in the industrial Plowshare program is intended to provide information about the application of nuclear stimulation of natural gas on a field development basis. Project Rio Blanco involves a field development program of natural gas in the Piceance Basin in Rio Blanco County, Colorado, about 50 miles north of Grand Junction. CER Geonuclear Company, working in cooperation with the AEC, is the industrial sponsor. The first phase of this project, conducted on May 17, 1973, used three 30-kiloton explosives spaced vertically in a single wellbore to fracture a thick section of gasbearing sands. The nuclear explosives designed specifically for this application were spaced at depths of 5840, 6230, and 6690 feet underground and were detonated simultaneously.

Further development to adapt the nuclear device to sequential firing will permit another project, Wagon Wheel, to proceed toward development of a natural gas field in the Green River Basin of Wyoming. The industrial sponsor for Project Wagon Wheel will be the El Paso Natural Gas Company. The project design involves the sequential detonation (a few minutes apart) of five 100-kiloton nuclear explosives emplaced in a vertical configuration in a single wellbore. No date has been set, however, for the conduct of this project.

In February 1973, the Kennecott Copper Corporation and the AEC signed a contract to study and evaluate in-situ copper leaching utilizing Plowshare technology. The study will investigate the possibility of fracturing a deeply buried low-grade copper deposit and then percolating an oxidizing leach fluid through the fractured rock. The leach fluid would then be pumped to the surface where the copper could be extracted.

For the industrial Plowshare program to become successful on a commerical basis, a number of problems still must be resolved. First, its economical feasibility must be such that it will provide adequate return to the risk capital. Second, the public must accept this new technology where perceived risks and social costs may outweigh benefits. Third, the protection of the public and the environment against possible damage must be assured. Fourth, several legal issues must be resolved, especially those related to state-federal powers, legal responsibilities, and idemnity measures.

IV. ASSESSMENT OF NEEDS

As pointed out previously, industrial Plowshare technology has progressed to the point that various proposals for its use are being given serious consideration by industry and the AEC. In the Western States, these uses relate primarily to obtaining fuels, minerals, and/or geothermal energy from ever deeper deposits as more readily accessible shallow deposits become depleted. The use of nuclear explosives might also be found to be the best way to create deeply buried cavities for storing or disposing of toxic wastes such as the radioactive "ashes" of nuclear reactors. In this section, the needs of the Western States that can best be served by nuclear means are assessed. However, it is important that each such use serve some particular kind of social need better than other known and available methods.

Of these several kinds of needs, those for fuels, and/or geothermal energy are rapidly becoming the most critical.[1] The basic characteristics of this so-called "energy crises" are summarized in the figure in Appendix B. This figure is based upon the rates of use of energy in the United States in 1970 according to Cook[2] and upon the remaining U. S. reserves of natural gas and oil according to Hubbert.[3] As indicated by the dotted trapezoidal areas, those reserves (which include estimates of all new deposits that are likely to be discovered in the future) could provide for only about 20 more years of use at their 1970 rates. The dashed line reflects an even more critical shortage of natural gas; about half of the remaining reserves occur in such deep highly-consolidated deposits that it cannot be extracted effectively with current production methods.[4] One important aspect of the energy problem is thus seen to be the need to develop substitutes for clean-burning natural gas that can well serve the "stationary" end-use needs for heat-energy in homes, offices, and manufacturing plants.

Neither geothermal nor direct solar sources of energy appear to offer much hope of serving more than a small fraction of the stationary heating needs within the forseeable future.[1] Neither can electricity from large remote electric power plants well serve the stationary needs because only about one-third of the latent energy of the fuels is convertible into

electrical energy. Nearly three times as much fuel would be consumed if heating needs were served electrically instead of directly by the fuels. It will thus be better to serve most of the stationary needs for heat energy until the turn of the century with the remaining deeply-buried reserves of natural gas and/or coal-gas.[1]

Plowshare technology provides one method for satisfying this need for natural gas. A natural gas production program which would recover 65 trillion standard cubic feet of gas from 2000 wells in Wyoming and Colorado over a twenty-three year construction period has been studied by scientists at the Lawrence Livermore Laboratory.[5] The annual production rate of this nuclear stimulated gas would amount to 2.5 trillion standard cubic feet in 1990, which represents about 6% of the total U.S. projected demand for natural gas. The availability of the special nuclear material required for such a program, however, will be influenced by its concurrent need in the nation's nuclear power program. An analysis of material resources has shown that the need for uranium-235 and plutonium-239 for this proposed natural gas stimulation program could be as much as 5% to 10% of the requirements of the civilian power program.[6] Limitations on the supply of special nuclear material for nuclear explosives may well prohibit a rapid commitment to natural gas stimulation in spite of the demonstrated need.

Also, there is still some question concerning the net gain of usable energy to be obtained by using one energy source (fissionable material) to extract another energy source (natural gas). An analysis has shown that the energy gain may be as low as zero or as high as a factor of ten; the degree of gain depends upon the efficiency of nuclear material utilization in the nuclear device.[6] Because of classification restrictions on detailed information about nuclear devices, it cannot be demonstrated here that there is a net energy gain in using fissionable material for natural gas stimulation and that the need for its use is thus in the nation's overall best interests. Scientists at the Lawrence Livermore Laboratory have studied this energy tradeoff, however, and have indicated that the net energy gain is indeed positive.[7]

The other needs that might well be served with nuclear explosives do not appear to be as urgent nor as extensive as the need to stimulate deep gas production. For example, the use of nuclear explosives to stimulate the recovery of geothermal energy in deep dry rock presents many uncertainties and can well be deferred until after the nuclear technology for gas stimulation and the technology of utilizing the shallower souces of geothermal energy have been fully developed.[8] Similarly, the use of nuclear explosives to extract deeply buried minerals can well be based upon the experience gained in their use to stimulate deep natural gas production.[1] On the other hand, the use of Plowshare technology to create deep underground storage cavities for natural gas and for high-level radioactive waste disposal may well prove to be the most beneficial application. But these applications are still under study and can thus profit from the actual experience gained in natural gas stimulation.[9,10]

V. ENVIRONMENTAL IMPACT

Because the use of nuclear explosives in industral applications involves potential risks to the public and insults to the environment, long-range and short-range harmful effects are considered in this study to provide a basis for project evaluation prior to such an event. Impact, as used in this section, does not include the many beneficial effects to the public and environment that could accrue from industrial uses of nuclear explosives. The principal sources of environmental impact associated with nuclear explosives are, therefore, seismic waves and radioactivity.

A. Seismic Waves

With the detonation of an underground nuclear device, large amounts of energy are liberated. Most of this energy exists as heat which produces cavity temperatures of several million degrees. These high temperatures cause vaporization of the rock in the cavity near the detonation point, and create a high pressure zone. This pressure zone rapidly expands and loses most of the initial explosive energy in the process of melting and crushing the surrounding rock. The rapid expansion of the pressure zone causes a shock wave to form which travels outward in all directions from the point of detonation. After the wave has passed through the plastic deformation zone, the remaining energy is carried by a seismic or elastic wave which resembles an earthquake shock wave. This seismic wave carries between two and five percent of the total initial explosive energy.[1]

Comparison of Earthquakes and Explosions

Two types of waves are associated with seismic disturbances: the P-wave (primary wave) and the S-wave (secondary wave). The S-wave consists of movement sideways or up and down with respect to the direction of wave propagation (a transverse wave, like a water wave). The magnitude of the S-wave is directly related to the magnitude of ground motion resulting from a disturbance. The P-wave consists of vibrations in the direction of wave propagation (a longitudinal wave, such as the motion following the release of a compressed spring).

The difference between earthquakes and underground nuclear explosions are not in the type of waves produced but rather result from the differences

in wave magnitudes. Earthquakes produce both S- and P-waves of sizable magnitudes. Because of the large S-wave magnitude, earthquakes generate significant ground motion near the point of the disturbance (epicenter). Nuclear explosions also produce both S- and P-waves; however, the initial radiating signal consists only of P-waves. When this signal encounters a discontinuity or boundary, an S-wave is then generated. This results in the low S-wave magnitude characteristics of underground explosions. Thus, less ground motion is associated with an explosion than with an earthquake having the same seismic energy.

In determining the magnitude of a seismic disturbance, the strength of the P-waves is calculated. Thus, an explosion whose P-wave strength is equivalent to the P-wave strength of an earthquake will have the same magnitude as the earthquake. However, in that an explosion's S-wave activity is small compared with that of an earthquake, less ground motion will be associated with the explosion than with an earthquake of equal magnitude. In fact, the amplitudes of surface waves from earthquakes are several times larger than those from underground nuclear explosions.[2] Also, earthquakes are more damaging because the energy release lasts for a longer period of time (seconds to minutes), whereas the energy release time for a Plowshare explosion is less than a second. Therefore, a nuclear explosion of Richter magnitude five does not have the same potential for causing, through ground motion, damage and injury as does an earthquake of Richter magnitude five. Further information on seismic magnitudes including energy-magnitude relationships can be found in References 3, 4, 5, and 6.

Effects of Seismic Waves on Geological Formations

The basic effect of seismic waves is the creation of subterranean and surface motion. In alluvium, clay, loose soil, and shale, most of the seismic energy is dissipated in cracking and breaking the rock. Much of the total seismic energy is thus lost in these "soft" rocks and is not available for further propagation. Significant amounts of energy, however, also reflect from cracks and discontinuities to the surface and result in ground motion. Because granite and other "hard" rocks are not easily cracked or broken, only a small fraction of the wave's energy is reflected to the surface and little ground motion occurs.

The worst geologic composition for the creation of large amounts of surface gound motion would be a detonation area surrounded by granite or other "hard" rock out to a relatively large distance (greater than five miles). This configuration allows the seismic waves to propagate with little energy loss over a large distance. If there are geological discontinuities some distance away from the detonation area located on alluvium or other "soft" rock, significant surface motion will then occur in this region. Thus, an area which may seem far away, twenty to thirty miles from the point of detonation, may not be free from potentially damaging ground motion.

The effects of the seismic waves on strata located several hundred feet below ground level (particularly oil shale deposits) are still being researched and have not been completely documented. According to the oil shale companies, the seismic waves may cause rock joint disruptions and widespread geologic stresses which would render mining for oil shale and associated minerals impossible.[7] On the other hand, scientists at Lawrence Livermore Laboratory see no possibility of fracturing either by direct mechanisms or by spall effects at depths greater than 400 feet below the surface.[7] In that oil shales of value generally lie at depths greater than 1000 feet, spallation effects should pose no threat to the development of oil shale. Potential spallation must be considered, however, when mineral deposits occur in the same general area as potential Plowshare projects.

Effects on Buildings and Other Surface Structures

Ground motion at distances from ground zero is a function of the local geology, the yield of the blast, and the depth of the detonation. On the basis of experimental measurements from more than three hundred underground nuclear detonations conducted by the USAEC and the existing geological and mechanical conditions at a particular structure site, predictions of ground motion can be made with a good degree of accuracy. However, because of the possibility of unexpected amplification associated with a particular geological region, confidence limits must be imposed on ground motion predictions. Figure V-1 shows the comparison of predicted and measured ground motion for project Rio Blanco.[9]

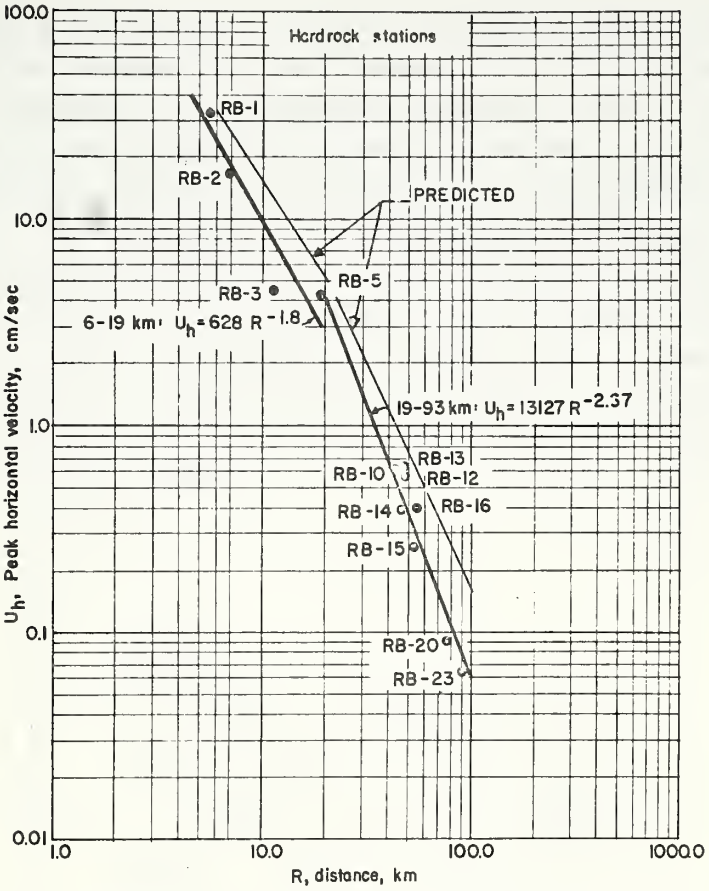


Figure V-1.[9] Observed Peak Horizontal Component Velocity, Project Rio Blanco

Structural damage predictions are based on a comparison of the predicted ground motion for an event with a structure's capacity to withstand that ground motion; allowances are made for the type, age, and condition of the structure.[10] The best predictive methods use evaluations of the event's frequency spectra in comparison with the effects of different frequencies on different structure types. The low-rise or ground level structures (one or two stories) seem to be most affected by high frequency seismic waves (waves with short periods); whereas, the high-rise buildings (ten or more stories) are most affected by low frequency seismic waves (waves with long periods). For most Plowshare events (medium yield devices deeply buried), the low-rise structures near ground zero and the high-rise structures away from ground zero will have the greatest probability of damage.

Ground motion thresholds for various types of damage to structures have been well documented in the literature.[11,12,13] Upon superimposing these thresholds on a graph of predicted ground motion for a typical Plowshare project, the relationship between expected damage and distance from ground zero for various explosive yields can be demonstrated (Figure V-2).[11,14,15] Uncertainties in both the damage thresholds and the predicted ground motion limit this diagram to only qualitative trends. Actual damage predictions must be made for each specific Plowshare project at a particular location. Such a diagram, however, serves to demonstrate that minor "architectural damage" (cracking of plaster, disturbance of bricks and concrete blocks, etc.) can be expected to occur 10 to 20 miles from a typical Plowshare detonation.

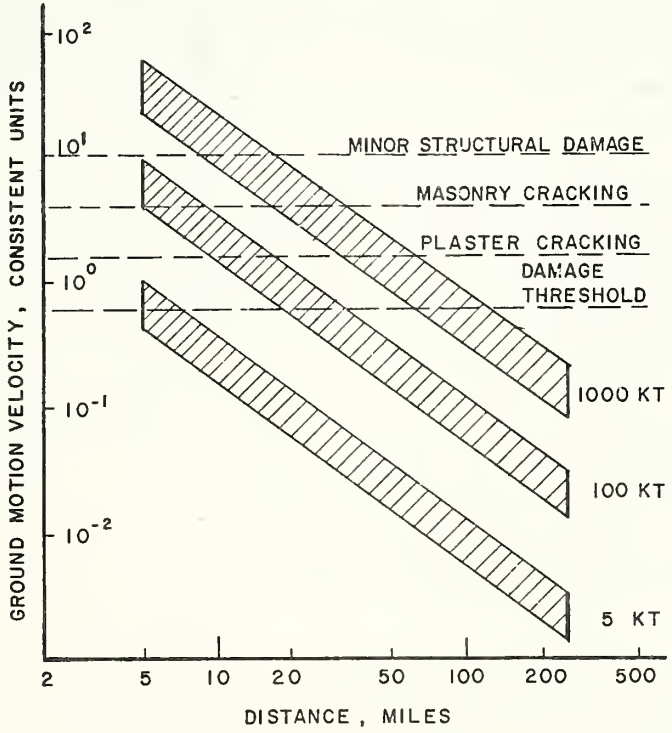


Figure V-2. Typical Seismic Damage Associated with Underground Nuclear Explosions

Perspective concerning damage from deep underground explosions can be obtained by comparing the degree of ground motion to be expected to the

design requirements of the Uniform Building Code.[6] Regions of the United States are classified as being in Seismic Zone 0, 1, 2, or 3, depending upon the degree of earthquake activity that can be expected to occur (see Appendix C). Bellamy and Brewer[16] have estimated that the seismic effects on buildings directly above a deeply buried explosion with a yield of 300 kilotons would typically correspond to the effects of earthquakes at the boundary between Seismic Zones 1 and 2 of the Uniform Building Code. Such estimates can be only typical of average conditions; in the most unfavorable conditions at a specific place, the effects of such a deep 300 kiloton explosion might correspond to those of the strongest earthquakes to be expected at the boundary between Seismic Zones 2 and 3. However, even if structures in a particular Seismic Zone do not meet the Building Code design requirements for that zone, this must not relieve a Plowshare project sponsor of his responsibility to cover any structural damages which occur as a result of the project.

It is of interest to note that the areas in Colorado and Wyoming being considered for nuclear stimulation of deeply-buried natural gas reservoirs fall mainly in Zeismic Zones 1 and 2. As pointed out in Section IV, natural gas stimulation will probably provide the initial experience in industrial Plowshare applications. The Seismic Zone comparison indicates that the yield of any one explosion might well be limited to 100 kilotons in which case, minor architectural damage is not likely to exceed that of earthquakes that can be expected to occur at that particular locality sometime in the future. Although building damage from a particular project may be minimized with even higher yields, the suggested limit of 100 kilotons per single detonation is a valid, though conservative, recommendation until additional experience has been obtained.

Experience with previous underground detonations and earthquakes has provided a basis for the development of several models which have been tested to predict ground motion and its effects on various types of structures.[4,12,20] The probability of unexpected damage to structures from underground detonations has always been very small and is becoming even smaller with additional experience. A certain amount of minor architectural damage (cracking of plaster, disturbance of bricks and concrete blocks, etc.) is

always predicted as a result of ground motion. If predicted damage is beyond acceptable limits, steps must be taken to strengthen weak structures, or, if necessary to make changes in the proposed detonation conditions (lower yield, multiple sequential detonations, etc.). Temporary evacuation of people from structures may be advisable as an added safety precaution. If any structural damage (directly affecting a structure's integrity) is predicted, the project and its procedures must be reevaluated.

The Rulison detonation resulted in 337 damage claims settled for a total of nearly $135,000 of which $97,570 was for property damage.[17] The other $37,000 was for losses such as lost production time in nearby mining operations. The majority of claims were for brick chimney damage and cracked interior plaster. The dollar damage to structures came within 88% of the predicted damage.

In anticipation of the Rio Blanco experiment, an extensive inventory and hazard assessment was made for structures out to a distance of 30 miles; these included buildings, bridges, tunnels, power and telephone lines, gas and oil and water pipelines, mines and quarries, railroads, hydraulic structures, airports, and roads. On the basis of this investigation, structural bracing and modifications were carried out prior to shot time. The unavoidable damage to approximately 170 structures in the area was estimated to be about $50,000.[8] After the actual detonation, however, structural seismic damage appears to be much lower than the maximum estimated. As of June 15, 1973, 72 claims had been settled at a total cost of $13,425.[9] For the Wagon Wheel experiment, preliminary indications are that the sequential detonation of five 100 kiloton explosives could cause minor architectural damage to about 200-400 residential, public, and commercial structures and associated buildings for which repair costs could be about $65,000.[18]

Possible Earthquake Stimulation by Seismic Waves

No relationship has yet been established between underground nuclear explosions and the triggering of a large magnitude earthquake. The possibility of triggering natural earthquakes through nuclear detonations has been studied at the Amchitka Island test site which is situated on one of the world's more active fault lines. Seismic effects of the Milrow and

Cannikin events at Amchitka showed no indication of increased seismic sensitivity or the initiation of a dangerous earthquake near the Aleutian Islands.[19] Even if such an event did occur, it could be argued that the explosion did not cause the earthquake but merely initiated it earlier than it would have normally occurred. The safety of a region's inhabitants might even be enhanced if a quake were triggered at the time safety precautions associated with a nuclear detonation had been taken.

Past nuclear events have created small after-shocks containing only a fraction of the energy carried by the seismic waves resulting from a nuclear detonation. These shocks, which resulted from small movements along pre-existing fault planes, constituted the release of natural strain (deformation) energy. Ambient seismic activity at Rulison was monitored by one instrument for over a year before and after the detonation. Five monitoring stations were continuously in operation for a period from a few days before the detonation to 20 days afterwards.[20,21] Many small aftershocks were observed within a few minutes after the detonation; all orginated within three thousand feet of the Rulison location. Further monitoring for twenty days at distances out to sixty miles indicated twenty-seven seismic events; of these, fourteen were less than sixty miles from the Rulison emplacement well.[21] It is expected that an explosion in the one hundred kiloton yield range would generate no more than a few dozen aftershocks, none of which would have a Richter magnitude of greater than 3.0 (compared with a Richter magnitude of 5.5 for the original explosion). The aftershocks should cease within a few hours, and the total seismic energy released in all these shocks would be substantially less than that from the original one hundred kiloton event.

Thus, chance of a Plowshare detonation triggering a major earthquake appears slight. The associated aftershocks are of such a small mangitude that they should not increase the seismic hazards associated with the project detonation. Therefore, no additional safety precautions should be required to account for the seismic effects of earthquake triggering, strain release events, or aftershocks.

Environmental Effects of Ground Motion

Ground motion resulting from an underground nuclear detonation can have effects on water quality, vegetation, animal habitats, and man-made projects.

At Project Rulison, seismic effects did not permanently impair streams or water bearing formations in the vicinity.[22] A transient increase in stream flow occurred in one creek followed by a gradual subsiding to normal conditions. The increase was believed to have been caused by compaction of sediments in the stream beds and the water-bearing soils which supply surface springs. Another effect was a temporary increase in stream turbidity and some stream diversion associated with the sloughing of stream banks.

Some localized damage to existing vegetation could occur from rock slides on very steep terrain or from disruption of root systems which penetrate soil and rock layers. A number of rock slides occurred in connection with project Rulison, but the damage to vegetation was minimal and might properly be classified as "microenvironmental" because of its limited geographic scale. Terrestial shock from nuclear testing in Nevada has been reported to have an adverse effect on some species of vegetation including pinon, pine, juniper, and sagebrush located near the detonation.[23] The impact of ground motion on vegetation is basically confined to a few trees and plants and is not widespread.

The greatest effect of a detonation on animal habitats is the possibility of creating seiches (up and down surface oscillation in a partially or completely landlocked body of water) which produce extreme pressures for short time periods. In that the periods of seiche oscillations do not correspond with the normal ground motion periods from explosions, there is little chance of creating a seiche. However, with the large ground motion near ground zero, pressure waves could be created in shallow water which would have the same effect as a seiche. Unless a lake or pond lies very close to ground zero, little impact from seiches would be experienced.

The possible effects on man-made projects include damage to roads, dams, gas lines, and utility and telephone lines. During Project Rulison no roads were broken up; but, because the possibility of rockslides onto the highways did exist, the roads were blocked for about an hour at

detonation time. Few rocks were found on the highway, but potential rockslides still presented a safety problem.

B. Radioactivity

Sources of Radioactivity

The principal sources of radioactivity left after the detonation of a nuclear explosive can be divided into three categories: unburned nuclear fuel, nuclear reaction products, and neutron activation products. Each of these three types of radioactivity will be discussed briefly both for fusion and for fission explosives.

No nuclear explosive will consume or "burn" all of its available nuclear fuel.[24] The tremendous energy which the nuclear explosive releases causes a significant fraction of the fissionable material to be scattered as explosion debris before all of the nuclear fuel has reacted. Thus, in a 100 kiloton, all fission explosion with material efficiency of 30%, about 13 kilograms of nuclear fuel (about 800 curies for plutonium) remains behind after the detonation. The radioactive emissions from both uranium-235 and plutonium-239 consist of alpha particles (helium nuclei) beta particles (high energy electrons) and gamma radiation (similar to x-rays) with some neutrons from spontaneous fission. The primary nuclear fuels in a fusion explosive are deuterium and tritium, the two heavy isotopes of hydrogen. As in the case of the fission explosive, not all of the fusion fuel has time to react before the tremendous pressures and forces involved in the explosion blow the reacting mass apart. Residual deuterium is non-radioactive and relatively harmless to living organisms. Tritium, however, is radioactive (emitting low energy beta particles) and is considered to be of radiological significance. It has been reported that from 5,000 to 20,000 curies of residual tritium per kiloton of explosive energy is produced by a fusion device.[25]

The energy yield of a fission explosive is achieved through the fission or splitting of trillions upon trillions of individual nuclei. The fission of 1.45×10^{23} nuclei of a suitable fissionable material will result in the release of 1 kiloton of explosive energy. Each nucleus which

experiences fission leaves behind two "fission fragments." There are about 40 different ways in which the nucleus can split; therefore, 80 or so different fission fragments are formed as a direct result of the fission process. Most of these fission fragments are the nuclei of radioactive isotopes of lighter elements whose mass numbers vary from 75 to 160. The radioactivity from these fragments usually results in the emission of beta particles and gamma radiation. The initial decay (or daughter) product is usually also radioactive and it, too, will decay in turn to another isotope of a new element. Three or four successive stages of beta-gamma decay are usually required before a final stable decay product is obtained. Over 200 different isotopes of 36 different elements have been identified in the debris (radioactive residue) of a fission explosion. The entire mixture of fission fragments and decay products is given the general name "fission products."

Every current fusion explosive must have a fission trigger, because nothing else will work as a practical "sparkplug" to set off a fusion reaction. This means that all nuclear explosives will have some fission yield; consequently, even a fusion explosion will have unburned fission fuel and fission reaction products left after it is detonated.

Specific information concerning the exact fission product inventory with respect to time after a given fission explosion is necessary for safety studies. Digital computer calculations have been utilized to provide this information, and several fission product codes are currently available. Most of these codes are designed for reactor applications; however, with appropriate modifications and reservations, some have been applied to calculations of fission product activity after an explosion. Lists of such calculations are presented in a number of references.[8,12,14,18,26] These lists are for generalized fission explosions and do not necessarily represent the actual fission product activity to be expected from a specific Plowshare explosive, although they do give a general indication of what to expect. From these, it is easily seen that the total fission product inventory can be significant even 6 months after a nuclear detonation. (See Appendix F.)

When any nuclear explosion occurs, significant numbers of neutrons are produced as a by-product of the nuclear reaction. If allowed to escape into the surrounding environment, these neutrons can create a significant amount of radioactivity in the medium by neutron activation. When the nuclear explosive is detonated underground, the amount and quantity of activation products formed will depend upon the chemical composition of the earth and rock surrounding the explosion. Lists of radionuclides formed by nuclear explosions in shale and sandstone are also presented in the literature.[8,18,26] Such lists are not generally applicable to any Plowshare project, however, because small variations in the amounts of trace elements present in a geological formation can have significant effects on the neutron-activation products formed by a nuclear explosion. Tritium, a radionuclide of considerable importance, is produced by neutron activation in a medium which contains trace amounts of lithium. In rock with a lithium content of 30 parts per million (by weight) some 1 to 3% of the neutrons which escape the explosion will produce tritium.[25]

Much effort has been put into the reduction of the amount of neutron activation products produced by a nuclear explosion. The most common method is to surround the explosive with a shield which will absorb the escaping neutrons and prevent them from reaching the medium and subsequently producing activation products.

Pathways to the Environment

The environmental importance of the radionuclide sources described above will depend upon the amount that might reach the biosphere. Potential pathways for radioactive contamination from industrial Plowshare projects will be evaluated in this section.

Atmospheric Contamination: Two types of accidental release of radioactive material to the atmosphere can occur. One, called "prompt venting" or simply "venting," occurs rapidly and involves the release of non-condensable gases and particulate matter. The other, called "seepage," involves the slow diffusion of noncondensable gases to the ground surface.

Prompt venting occurs when a path of low resistance to the ground surface is available to the high pressure reaction products from a nuclear explosion. The hot gases will drive up to the surface along this path of low resistance and transport fission products, unburned fuel, and neutron activation products to the atmosphere. The gaseous material present in the cavity at the time venting might occur is generally composed of water vapor (from moisture in the melted or vaporized rock); carbon dioxide (from heating of carbonate rocks such as dolomite); various isotopes of krypton, xenon, and iodine (from fission products); and tritium or tritiated water (from unburned fuel and neutron activation products in a fusion explosion, or from fission products and neutron activation products in a fission explosion). High pressure will force this gaseous material and perhaps parts of the molten lining out of the cavity and to the surface. As the molten material leaves the cavity, some of it would tend to solidify and be released to the atmosphere as particles.

The role which natural cracks, crevices, and fissures, in the earth's surface play in venting is not completely understood. Under certain conditions venting has occurred through ground fissures or crevices, but the presence of these fissures does not always mean that venting will occur. In many cases, it is thought that the complicated pressure and shock waves formed by the explosion actually close off pre-explosion cracks, crevices, and fissures.

Seepage of radioactive gases from the explosion cavity is a slower (and usually less serious) release of radioactivity. Seepage may begin as early as a few minutes after detonation or as late as several hours. It could last for a few hours or as long as several days. By the time the cavity gases have worked their way up through several hundred to several thousand feet of rock, they would be highly fractionalized, i.e., the relative composition of the escaping gases will be different than the composition of the cavity gases. Certain isotopes present in the cavity would be absorbed or adsorbed as they pass through the rock and might disappear entirely by the time the gases had reached the surface.

What is known about accidential releases of radioactivity to the atomsphere from venting or seepage has been derived from experience in

weapons testing at the Nevada Test Site (NTS) at generally much shallower depths than those proposed for most industrial Plowshare applications. The data available therefore for predicting the probability of release and the quantity and composition of radioactivity released are not directly applicable to Plowshare projects. Such accidental releases are considered to have a much lower probability in industrial Plowshare applications and are not even considered credible by some scientists in the particular case of natural gas stimulation. Experience with weapons testing and Plowshare cratering experiments, indicates that less than 0.5% of the total radioactivity produced would escape even if a prompt venting accident were to occur.[20,26,27] The radioactive nuclides most likely released would be the gaseous elements: xenon, argon, krypton, iodine, and tritium.

The potential for prompt venting from an underground nuclear explosion is generally assessed in terms of scaled depth of burial (SDOB).[12,26,27] This quantity is obtained by dividing the actual depth of burial (DOB) by the cube root of the explosive yield in kilotons:

$$SDOB = \frac{DOB}{W^{1/3}}$$

The minimum scaled depth of burial for contained underground experiments at NTS is 350 feet per $kt^{1/3}$. Of 190 underground test shots at NTS since 1961, ten had a significant leakage (a total release to the atmosphere of more than 100 curies of radioactivity). None of the tests with an SDOB greater than 600 $ft/kt^{1/3}$, however, exhibited leakage.[27] To minimize the possibility of prompt venting from an industrial Plowshare explosion, therefore, a reasonable limitation would be twice the minimum SDOB used at NTS, i.e., 700 $ft/kt^{1/3}$. This limitation would require actual minimum depths of burial as shown below:

Yield (kilotons)	Minimum Depth of Burial (feet)
10	1510
25	2050
50	2660
75	2960
100	3260

In a prompt venting accident, the initial spread of radioactive material would be dependent upon meteorological conditions and the local geographical area. Generally the radioactive fallout area is restricted to a very narrow corridor in the prevailing wind direction. Example radiation isodose lines for a 100-kiloton explosion followed by a postulated 0.2% to 0.5% release of radioactivity are shown in Figure V-3. For a discussion of the biological significance of such dose values see page V-19. It must be emphasized that these radiation doses assume many days of continuous exposure at a particular location downwind without any protective measures. This would not be a realistic assumption for direct exposures to humans under accident conditions. Nevertheless, this graph indicates that a venting accident of this magnitude could have a serious environmental impact out to distances of 10 to 20 miles along a relatively narrow area.

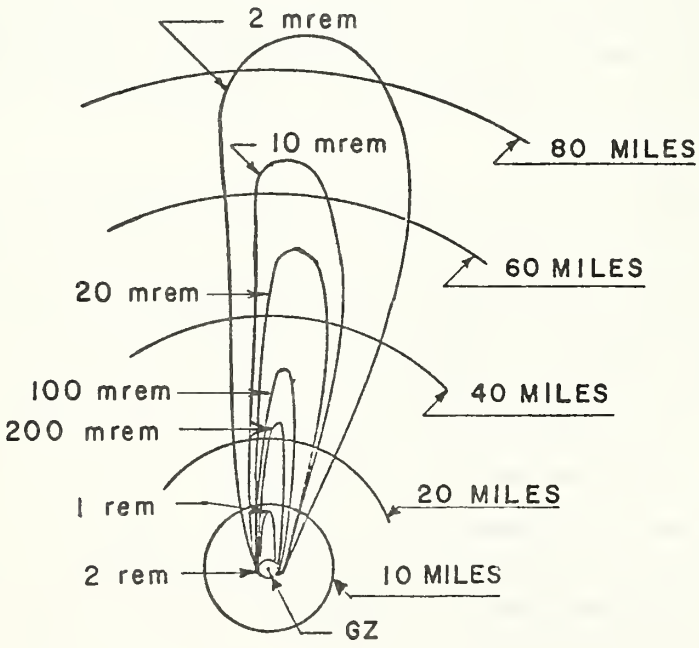


Figure V-3. Example Radiation Dose Curves for a 100 Kiloton Explosion, 0.2% - 0.5% Prompt Venting Release

Ground Water Contamination: Anytime a nuclear explosive is detonated underground, radioactivity can enter ground water directly if the explosion

occurs in or near a water zone or indirectly from water percolating downward from above. In either event, ground water will be the transport vehicle for the movement of radionuclides underground. Two basic types of radioactivity which can produce contamination in ground water are those associated with long-lived nuclear reaction products such as strontium-90, cesium-137, and calcium-45 and with gaseous nuclear reaction products such as tritium and krypton-85. Most of the radioactivity produced by an underground nuclear explosion (fission, fusion, or both) is trapped in the molten rock which collects at the bottom of the explosion produced chimney in the form of a glass-like puddle. This glass is very insoluble in water so that radioactive material can be expected to stay put. Of more immediate concern in ground water contamination are the noncondensable gaseous fission products and tritium which will be present in the chimney for a long time after the explosion. These gases can migrate out of the chimney and contaminate ground water. If seepage occurs and the gases pass up through an aquifer on their way to the surface, some contamination will undoubtedly result.

Three mechanisms will reduce the concentration of radionuclides in ground water: sorption, dispersion, and radioactive decay. Sorption greatly reduces the rate at which most radionuclides can move away from the explosion zone. As contaminated water migrates away from the rubble chimney, the radioactive elements will be adsorbed or absorbed (sorption) by the surrounding rock surfaces. The radioactive elements held by the rock may be later released to relatively uncontaminated ground water, but the net effect is to retard the migration of the radioactivity.

Fenske estimates that sorption alone will decrease the concentration of long-lived nuclear reaction products such as strontium-90 and cesium-137 by seven orders of magnitude before they can move outside the explosion zone.[28] (Explosion zone is defined as the rubble chimney and fractured area immediately surrounding.) The effect of sorption on tritium is usually neglected; tritium will generally move almost as fast as ground water in the form of tritiated water or tritium dioxide.

Dispersion is the effect of the contaminated water meeting and mixing with uncontaminated water. The radioactive water would be diluted and the

concentration of radionuclides thus reduced. This effect can be substantial in reducing the radioactive concentrations.

Radioactive decay will affect the concentration of contaminants with the passage of time. The elapse of 10 or 15 half-lives are sufficient for radioactive decay to reduce the activity of the most important nuclides to insignificant levels. For long-lived fission products, however, this number of half-lives amounts to many years. The true significance of radioactive decay in reducing the concentration of radionuclides in ground water would therefore be determined by how long the water took to get to a discharge area; this time period is governed by ground water flow rate.

With the exception of the possible use of nuclear explosions for water management, ground water migration in the vicinity of most industrial Plowshare applications is extremely slow (200 to 800 feet per year).[12,28] Radioisotopes such as strontium-90 and cesium-137 are strongly sorbed by rock surfaces; therefore, the migration of these contaminants will be even much slower than the flow of ground water. As previously noted, sorption of tritium will be negligible, and it will move at about the same rate as ground water. Even assuming no sorption, or dispersion, however, Fenske calculates that the concentration of tritium in contaminated water, from an underground 1 megaton all fusion explosion, moving at a flow rate of 100 meters per year would be below the maximum permissible concentration (mpc) in drinking water before the water could move 8.8 miles from the explosion zone.[28] Similar calculations predict tritium concentrations below mpc values at a water well 6.5 miles from the Rio Blanco project.[8] It is also of interest to note that, after 14 years of underground testing of nuclear devices at NTS, no radioactivity above normal concentrations has been detected at any springs or wells in Nevada.[27]

In summary, contamination of ground water in industrial Plowshare projects should not present a significant environmental hazard, if project planning assures that contaminated water does not reach a site of human consumption before the concentration of radioactivity has decreased to negligible levels. Still, a safety program must include sampling of water sources both before and long after a detonation, and provisions must be made to assure that contaminated aquifers are not used by man for many years.

Product Contamination: Radioactive contamination of the end product of an industrial Plowshare project (e.g., natural gas, geothermal steam, copper ore, etc.) will of course depend upon the particular application. The two radionuclides of principal concern in product contamination for natural gas stimulation are krypton-85 and tritium. Both are present in sufficient quantities and have long enough half-lives to pose a hazard. It is generally assumed that the gas released by this method will be consumed, at least partially, in individual households. Two hypothetical studies have been made to evaluate gaseous product contamination - one for Gasbuggy and the other for Rulison.[29,30] The study for Gasbuggy predicted a maximum exposure from contaminated natural gas of 2.2 mrem/year for residents of Los Angeles and 2.5 mrem/year for residents of San Francisco.

The calculational model used for Rulison indicated that the total potential dose that an individual would receive in a home in Grand Valley, Colorado, from an unvented gas stove and refrigerator operated with non-flared gas piped from the project would be 39 mrems the first year, would decrease to about 5 mrems the second year, and would decrease correspondingly after that. The same study estimated that the total dose an individual in Grand Valley would receive from the same appliances using gas taken from the Rulison well after the operational flaring of some 400 million cubic feet would be .03 mrems the first year and even lower doses in following years. The AEC has noted with respect to both cases that such conditions are hypothetical and are not representative of possible large scale future gas distribution from nuclear stimulated wells. Gas from a new well would probably be diluted with gas from older wells in which the radioactivity would be at considerably lower levels. Because of this dilution factor, it is currently thought that no flaring of gas from a new well would be necessary prior to its being connected to the distribution system.

In the case of nuclear geothermal stimulation, radioactive contamination of the product steam could present a significant problem. Non-condensible gases present in the steam of a thermal-electric plant tend to collect in the condensor. In natural fields, these gases are generally eliminated by venting to the atmosphere. In a nuclear stimulated geothermal

system, the operational venting of gases with radioactive components, primarily krypton and tritium, might be unacceptable. If a direct power cycle using steam from the cavity to operate the turbines were employed, contamination and deposition of radioactive materials, including strontium and cesium, throughout the entire working fluid system becomes an important consideration.[15]

In the case of copper leaching applications, appreciable quantities of some fission products, e.g., strontium-90, cesium-137, and ruthenium-106, are expected to be present in the chimney in leachable form.[20] Although only a small fraction of this radioactive material would be dissolved and carried to the surface, some radioactive contamination of the process facility will occur. Also, low level residual radioactivity of the copper itself (produced by neutron activation) may affect its distribution as a consumer product.

Radioactive Wastes: Radioactive wastes such as water or drilling mud can also cause radioactive contamination of the environment. In nuclear stimulation of natural gas, water produced in the gas stream will contain tritium in excess of acceptable concentrations, therefore, this water must be disposed of. Three alternative methods of disposal of the separated water have been evaluated: (1) reinjection of that water into the cavity, (2) use of an evaporation pond, and (3) burial in authorized waste disposal areas.[31]

Experience at Gasbuggy and Rulison indicates that upon reentering the well, no contamination occurred at the surface as a result of circulation of the drilling fluid. In Rio Blanco, to allow for the possibility of surface contamination during drillback, the drilling fluid will be handled in such a way that potential contamination will be minimized. During drillback and production operations, attention must also be given to contaminated equipment and material such as filter papers, swipe cloths, desicants, pipes, valves, and tanks.

Biological and Ecological Considerations

For industrial Plowshare projects, the consequences of the potential release of radioactivity to the environment must be carefully considered.

The bioenvironmental safety program must deal with the potential impact of all the effects of a nuclear detonation, including those of long-range consequences. The consequences considered must include (1) the potential exposure of people both to external whole body contamination and to internal radiation by way of food chains, (2) damage to wild life populations and to vegetations, and (3) general disturbances which may lead to undesirable ecological effects.

Radiation Safety Guidelines: For the general population (i.e., persons non-occupationally exposed) the Radiation Protection Guide limits whole-body exposure to radiation to a maximum of 170 millirems per year for any individual.[32] These Guides are recommended by the Federal Radiation Council (FRC) and the National Committee on Radiation Protection (NCRP) and have been formulated into standards and regulations by the USAEC. The significance of these Radiation Protection Guide doses can best be understood when they are compared to natural background radiation which results from radioactive isotopes being present in the ground, in brick and stone, in the air, and even in the body itself as well as that which results from radiation from cosmic rays. Natural background radiation doses to the general population vary from 120 to 160 millirems per person each year for different geographical locations. Diagnostic and therapeutic medical exposures to radiation add an additional 30 to 40 millirems per year to the average individual. Accordingly, it appears that the genetically significant annual dose from all sources of background radiation is on the order of 150 to 200 millirems. The maximum whole body dose of 170 millirems for individuals (in addition to background radiation doses) specified above in the Radiation Protection Guidelines is therefore about the same order of magnitude as total background doses.

In recent years, the Radiation Protection Guides have been criticized for at least two reasons. First, the radiation doses may seem high in the light of uncertainties concerning cumulative effects of low levels of radiation. Second, the Guides are often misinterpreted by the public as permissible doses which would have no deleterious biological effect on the persons exposed; this is not at all the case. At this point, it must

be assumed that any radiation exposure, even small doses in relation to natural background, may have a deleterious effect on humans; therefore, the Guides must be recognized as only those doses below which the FRC and the NCRP predict that the deleterious effects will be "acceptable," particularly with regard to long-term genetic damage. It is not surprising that the concept of "acceptable" varies considerably among various organizations and concerned individuals. The Federal Radiation Council was abolished in December 1970 as a part of a general reorganization of federal environmental programs and its functions were assumed by the Environmental Protection Agency (EPA). EPA will continually review the Radiation Protection Guides in light of any new findings or evidence and will make appropriate changes where necessary. A report issued in 1971 by the NCRP, however, contains recommendations that essentially substantiate the FRC Guidelines.[32]

Radioactive materials might enter the body by ingestion and by inhalation which would lead to internal exposure to radiation. The FRC has proposed Radioactivity Concentration Guides which are fundamentally equivalent to the Radiation Protection Guides for external exposure. These Concentration Guides are expressed as maximum permissible concentrations (mpc) of specific radioisotopes in air and in water.

Radiation Effects Upon Humans: In the benefit-cost analysis of industrial Plowshare technology, the risk of possible radiation exposure to humans is a prime consideration. A great many late effects from exposure to radiation have been described and of these the increased incidence of leukemia and life span shortening are considered to be the most sensitive.[33] In recent reviews, Storer[34] and Brent[35] concluded that life span shortening was the most sensitive test for long-term radiation effects. The best estimates of life shortening in man fall conservatively in the range of 1 to 3 days per rem for continuous exposure at very low dose rates.

Leukemia induction from radiation is probably the next most sensitive indicator of effect on the general population. Eisenbud recently reported that the epidemiological evidence suggests that a dose of 1 mrem delivered to 100 million people may produce a maximum of about 2 extra cases of leukemia over the lifetime of the exposed population.[36] The normal incidence of

leukemia in the U.S. population is about 70 cases per million per year. A recent report by a subcommittee of the National Academy of Sciences, which is exactly appropriate to this subject, calculated that 4 mrem to the entire U.S. population would produce from 3 to 15 additional cancer deaths annually (an increase less than 0.1%).[37]

The problem of genetic consequences of chronic low-level radiation exposure is less well documented. The mutational effect of radiation was demonstrated some 45 years ago, and it is still generally believed that any exposure results in some genetic risk, i.e., there is no threshold for genetic effects. The general current conclusion from all studies of the genetic effects of radiation seems to be that the risk per rem is probably less than for somatic effects (life shortening and leukemia induction).[38]

In general, normal Plowshare operations would probably increase background radiation in the vicinity of a project site less than two percent. Potential exposure doses from product contamination will depend on the type of project, but such exposures must be maintained as low as practicable. As discussed on p V-15, even a significant venting accident would expose a few persons in a small area to only a few hundred millirems, perhaps two or three times normal background.

Radiation Effects Upon Animal Life: Within those regions of the United States proposed for industrial Plowshare projects, many animal species are represented, but an assessment of hazards indicates only a few that would be of economic importance or endangered in any conceivable manner by low level radiation. Two general classes of animals are of economic importance - the domestic or farm animals and the wild game animals. Domestic animals in the arid, low-population density areas where gas stimulation Plowshare projects are likely to be conducted will be largely cattle and sheep. The economically most important wild animals are the large ruminants: elk, deer, and antelope.

For the most part, in order to predict the effects of low level radiation on farm animals and the large wild animals, it becomes necessary to extrapolate from the elaborate calculations and tables that have been

developed for the human population and at the same time to recognize that these data have been generated in part from results obtained with mice, rats, and dogs. It can be concluded, however, that neither life span shortening nor tumor induction will have any real value as parameters to describe chronic radiation effects on livestock or wild game animals.[33]

Farm animals presumably would be as susceptible as man and laboratory animals to radiation-caused mutations. The practical significance, however, of such rarely occurring mutations would be slight because, unlike with the human population, selection is practiced continually in livestock. The occasional occurrence of a rare gene in wild animals would be even less likely to be observed. Because of prevailing animal management practices, therefore, low-level radiation is unlikely to have any significant influence on the three factors that are considered important in human exposure: life shortening, tumor production, or genetic damage.[33] The problem of radiation exposure to farm and game animals thus becomes one of interpreting shorter term effects of radiation. Some studies of these effects have been made on farm animals, but the effects observed have occurred only at doses many times greater (hundreds of rems) than the minimal doses that produce gene mutations, tumor induction, or life shortening in laboratory animals.

The food chains of interest in the animal economy would be meat from cattle, sheep, pigs, and wild animals and milk from dairy cows. If tritium is taken to be the principal radionuclide of concern, this simplifies consideration of the animal food chain contamination. Tritium is not concentrated in any tissue or organ, unlike the three fission products that are of principal concern in the food chain and which are each concentrated as follows: strontium-90 in bone, iodine-131 in the thyroid, and cesium-137 in muscle tissue. Another factor which reduces the hazard from tritium is that in animals, it has a relatively short biological half-retention time ranging from three to seven days. Because of the biological hazard of the uptake of radioactive iodine, especially by children, particular attention must be paid to potential radioiodine in cows' milk.

Game fish, a form of animal life of considerable economic importance, may also be found in some of the areas of interest for industrial Plowshare

projects. Qualitatively, fish respond to radiation the same as terrestrial animals.

Radiation Effects Upon Plant Life: It is well documented that radiation affects plant communities.[38] The sensitivity of individual plant species and that of the total plant community range from that observed for mammals to much higher values (i.e., less sensitive). It is a general rule in radioecology that as the plant community becomes more diversified, i.e., contains a greater number of species, the radiation resistance increases. At least 1000 rads are necessary to produce moderately serious effects on any total community.[38] From this, it is concluded that no measurable effect on natural or agricultural plant systems should be expected to result from the radiation from industrial Plowshare projects.

In summary it is concluded that if the potential dose commitments postulated for normal Plowshare operations are realistic, i.e., several millirems, there is no justification in expecting either observable acute or chronic effects of radiation on the human or plant and animal populations which will be at risk. In the case of accidental venting or seepage, planned control measures must protect human populations. Only minor effects would be expected for the local animal populations, although again planned control measures must protect against potential food chain contamination.

C. Other Environmental Effects

Drilling, excavation, and construction have been shown to result in more ecological impact than the underground nuclear detonation. The actual operations of environmental significance would depend upon the particular Plowshare site under development; however, some of the more common construction activities which must be examined for their environmental and, in some cases, aesthetic impact include the following:[31]

1. Drilling for geological and hydrological studies, nuclear explosive emplacement, and radiation monitoring.

2. Land excavation and filling operations for access roads, rail tracks, pipe lines, transmission lines, canals, cooling ponds, and building sites.
3. The movement and storage of building materials and the building of temporary housing for construction workers.
4. Disposition and loss of materials and effluents resulting from construction activities.
5. Plant design and layout compatibility with surrounding environment.

As can be seen, most of these activities are not uniquely associated with Plowshare projects.

The industrial activity and noise would tend to temporarily displace some animals and birds in the site vicinity. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, fishing and camping opportunities on these lands.

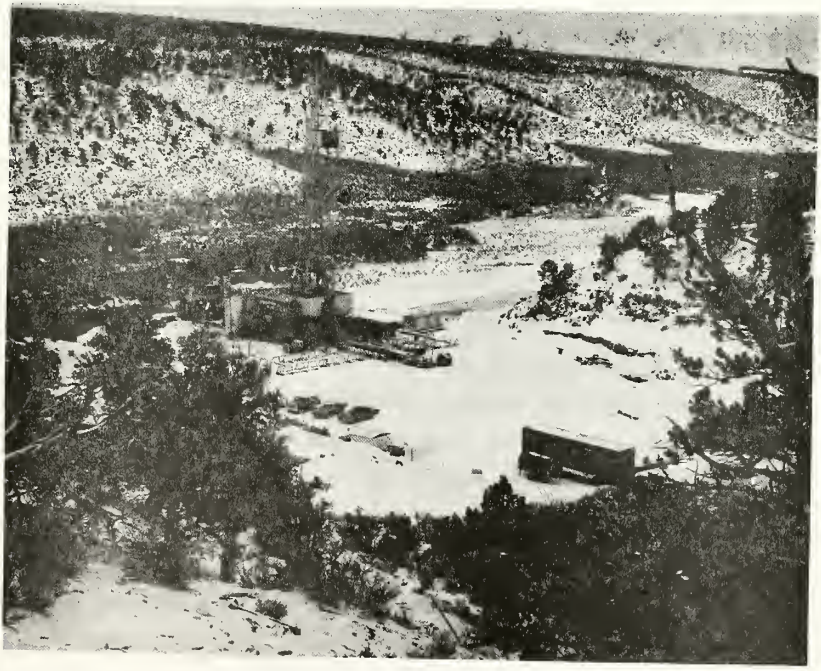


Figure V-4. Emplacement hole being drilled for Rio Blanco natural Gas Stimulation Project.

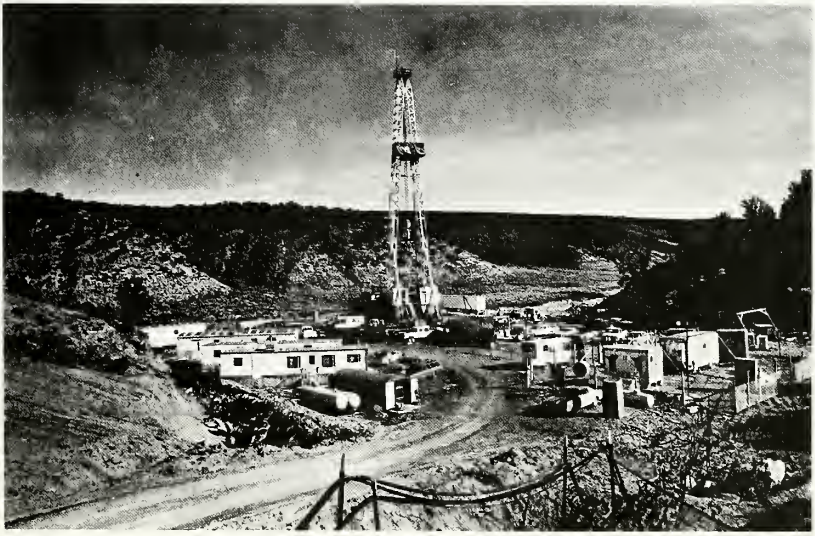


Figure V-5. Rio Blanco site in western Colorado in preparation for nuclear stimulation project, May 1973.

D. Environmental Safety Program

No industrial Plowshare project can proceed unless an adequate safety program has been planned to ensure that all reasonable safeguards have been employed to protect public health and property and to minimize distrubances that may upset the ecology of the region. Planning for safety must therefore involve a study of every possible impact of a project before, during, and after detonation. Extensive pre-shot information must be gathered about plant, animal, and human populations and their interrelationships as well as about the hydrology, seismology, geology, geography, climatology, and meteorology of the region. A detailed set of procedures for environmental surveillance must be established. The environmental impact report prepared by the industrial sponsor in compliance with the National Environmental Policy Act should cover the environmental impact on the entire area of proposed development for a Plowshare project. The report should also cover the

disposition of the depleted site. The potential role of the States in the approval of such safety programs and procedures is discussed in Section VIII. The USAEC has a sequential set of safety reviews which are conducted at four separate times in the planning stages of an industrial Plowshare project:[39] (1) After a preliminary assessment of the effects anticipated from the explosions, (2) after the environmental statement is prepared, final effects evaluations are completed, and the project plan is finalized, (3) after the site is prepared and everything is ready for emplacement of the explosive, and (4) just before detonation is authorized. A fifth safety review should take place after detonation to compare results with pre-shot predictions and evaluations.

Ground Motion Safety

During the planning stage of a Plowshare project, a survey must be made of all engineered structures (buildings, bridges, dams, tunnels, transmission lines, pipelines, mines, gas and oil wells, water wells and springs, airports, railroads, and highways) within the area where significant ground motion is predicted. Based on the techniques described earlier in this Section, an estimate can be made of the probable damage that could result from the anticipated ground motion. An assessment of potential damage from resulting landslides, avalanches, and rock falls must also be undertaken. All possible care must be taken to minimize architectural damage by predetonation preventive maintenance and bracing. To assure public safety at the time of detonation, it may be temporarily necessary to close roads and railroads to traffic, to evacuate buildings, and to halt mining operations at some specified locations.

The basic tool used in ground motion measurements is the seismograph which was originally developed to determine the location and magnitude of earthquakes. Rather than being used as warning devices, as are radiation monitors, seismographs are used to obtain data for correlation with predetonation predictions and for verification of damage caused by ground motion. The natural seismic activity in the region of a proposed Plowshare project should be well established before detonation. Seismic monitoring must thus be required both before and after each Plowshare detonation.

Radiological Safety

The basic purpose of the radiological safety program is to assure that radioactivity resulting from industrial Plowshare detonations does not endanger public health and safety. Appropriate procedures must be established for both surveillance of potential radioactivity releases and for protective action should a radiation release occur.

Measurements to determine the presence of radioactive contamination on or near the ground is generally accomplished with two basic types of instruments: An "active" beta-gamma radiation monitor, which provides a continuous indication of radiation exposure dose rate, and "passive" radiation sensitive dosimeters which measure total accumulated doses of radiation over a period of time.

During the planning stage of an industrial Plowshare project, a thorough natural background radiation survey of the proposed area and its surroundings must be conducted. A network of monitoring stations for air, soil, water, vegetation, and milk must be set up. This background survey should continue through all four seasons, and the data should be taken at least twice for statistical accuracy.

At the time of the nuclear detonation and for some period afterwards, a surveillance program must maintain a continuous assessment of radioactivity levels. Atmospheric and ground water monitoring must be carried out both before and after each Plowshare detonation at sufficient locations and for durations long enough to demonstrate definitely that neither venting or seepage into the atmosphere nor radioactive contamination of ground water occur. If this surveillance indicates that a significant release of radioactivity has occurred, planned control measures must be undertaken immediately to protect the general public.

In industrial Plowshare projects, it is necessary to drill back into the rubble chimney at some time after the nuclear detonation. The radiation surveillance program must continue through this phase of activity as well as through the production phase of a particular project.

Ecological Safety

For any industry the EPA requires that all steps be taken to minimize disturbances that may lead to undesirable changes in ecological systems (relationships between living things and their environment). The industrial sponsors of a Plowshare project must therefore outline procedures to minimize harmful changes which might arise from human activities at the project site, construction activities, and direct effects from the nuclear explosion. After the detonation, surveys of the area must be made to evaluate any damage that may have occurred and steps must be initiated to correct any undesirable ecological consequences.

VI. IMPACT ON LOCAL COMMUNITIES

Employment and Taxes

Many people believe that the development of Plowshare industry would increase job opportunities, incomes, tax revenues, and social services. The addition of such industries might appeal to several western states such as Utah, Wyoming, and Idaho which have been losing about 50% of their college graduates to other states because of lack of job opportunities. However, while the anticipated increase in employment and tax base sounds attractive, there is evidence that communities which experience rapid growth also frequently experience severe strain on the public purse. While public services increase, the property owner's tax bill often rises even faster. A study by Derr and Kasper of the effects of growth on local services and public finance found that costs frequently increased faster than benefits gained from the new services made available.[1]

New industries like Plowshare would usually bring new residents into the local community (rather than employ local residents) who are accustomed to a higher level of public services than the community had been providing. Ehrlich and Ehrlich argue that "Among the saddest phenomena of our times are the attempts by politicians and chambers of commerce to attract industry and developers to their areas to broaden the tax base. The usual result, when the dust has settled, is that the people who previously lived in the area have a degraded environment and higher taxes."[2] This issue can be approached by study of the prospective gains in a particular community where such an industry is proposed. The state could then take appropriate measures to ensure that the communities most vulnerable to Plowshare risks also fully participate in the socioeconomic benefits.

One particular Plowshare application does not appear to be an employment intensive industry for local communities. Excerpts from material presented to the Rio Blanco Planning Commission in Meeker, Colorado, by CER Geonuclear Corporation on February 15, 1972, provided the following estimates:

Anticipated tax revenues that may be generated by Project Rio Blanco, assuming full field development is authorized, also are outlined in the attached information. Using the average 1970 property tax mill levy for Rio Blanco County of 48.42 mills, the estimate is that Rio Blanco will generate about $1.5 million in county, schools and other local taxes, and $1.6 million in state taxes each year for the next 30 years.

Employment levels expected during the phases of Project Rio Blanco are a little difficult to estimate accurately. However, the estimate for Phase I is that a maximum 135 persons will be employed for a period of several weeks. Many of these will be drawn from available labor in Rio Blanco County and surrounding areas. The completion of Phase I will be followed by a rapid drop in employment until such time as a go-ahead for Phase II is given, during which employment will reach about 100. A drop-off again will take place between Phase II and Phase III, followed by a build-up and then drop-off until full field development is initiated. During this final period, a regular staff of 75 to 100 will be at work with employment peaking at about a maximum of 250 for brief periods. Once the field is developed and on pipeline, about 12 persons will be required to monitor equipment.

Project Rio Blanco's developers will employ as many of the workers on the project as possible from the local labor supply. Most of the others will be specialized, temporary skilled and professional personnel that will live briefly in the area before moving on to another assignment. It is not anticipated that they will have families with them. The developers intend to work closely with Rio Blanco County and local officials, and authorities in surrounding areas to assess availability of temporary housing for these personnel and to plan jointly any additional housing that may be necessary.

The estimated overall capital investment in Project Rio Blanco is about $4.4 million in Phase I, $10 million in Phase II and $60 million in Phase III. In examination of these costs, it also is estimated that about 50 percent of the Phase I and more than 50 percent of the Phases II and III investment totals will be spent in Colorado. The intent of the project developers is to maximize the use of local labor, supplies and services during execution of Project Rio Blanco.

Environmental Quality

While development that promises more jobs and public services appears attractive, it almost always brings with it side effects of air, water, and noise pollution that sometimes contribute to an overall decrease in quality-of-life.[3] The emergence of Plowshare industries would not only pose a direct threat of radioactivity and ground motion damage but might also disturb the ecology currently enjoyed by relatively underdeveloped

western states. How valuable the environmental quality is to the local people in a certain community depends upon anticipated economic gains and the values held by the community at that time.

People in local communities in rural areas are not expected initially to value the quality of the environment as high as would people in urban communities. When socioeconomic changes take place, however, and expected gains disappear or only partly materialize, values often change. Small communities generally favor any type of economic development that promises more jobs and revenue for the local area without considering adverse effects on the quality of the environment. Opinion surveys conducted by the University of Colorado relative to the Rio Blanco project show that public acceptance was much greater in communities near the proposed project than in the larger population centers further away.[4]

Sociological Effects

The values of our society are changing, and uncontrolled economic-technological development is being questioned. The old attitude of "what is good for General Motors is good for America," is changing to "What is good for America is good for General Motors." The ecology movement is a good example of changing social values which can and do exert a considerable influence. This influence usually follows the typical pattern of moral-religious values that affect the political, which then in turn influences the economic-technological institutions.[5] However, in most feasibility studies, economic and environmental impacts on the local communities are usually considered to the exclusion of the sociological effects. The development of industrial Plowshare projects will present several problems which are primarily sociological:[3]

(1) Social problems, resulting from the influx of new people into a small community: social integration and political participation and influence,

(2) The distribution of benefits and costs among various groups within the local community,

(3) Personal inconvenience to the local population,

(4) The future of the community and its people after the Plowshare resource runs out.

Again, it should be noted that these potential sociological problems are not unique to Plowshare industries.

VII. LEGAL ASPECTS

Because of the control which the federal government exercises over nuclear materials, no detonation of any nuclear explosive device can take place without authorization by federal law. On the other hand, the legal powers of the states in relation to Plowshare activities are not as clearly defined. Therefore, every legal aspect of actual and potential interface between state and federal governing bodies must be identified and clearly defined if the states are to effectively exercise decision making and regulatory powers.

At the present time, the only authorization in federal law for nuclear explosions for peaceful purposes is that found in the sections of the Atomic Energy Act authorizing the Atomic Energy Commission (AEC) to conduct research and development (R&D) activities.[1] Under this authority, principally Section 31 of the Act, Plowshare experiments have been conducted at the AEC's Nevada Test Site, and four have been conducted at other locations: Project Gnome, near Carlsbad, New Mexico, in 1961; Project Gasbuggy, near Farmington, New Mexico, in 1967; Project Rulison, near Grand Valley, Colorado, in September 1969, and Project Rio Blanco near Meeker, Colorado, in May 1973. An additional R&D experiment, Project Wagon Wheel has been proposed for western Wyoming.

No commercial application of Plowshare technology, of course, can be undertaken without first securing the necessary authorization by federal legislation. A bill to make possible the commercial utilization of Plowshare technology was first introduced in Congress by Representative Craig Hosmer in 1968; in modified form the bill was reintroduced in the Ninety-Second Contress, but it was never brought to the floor.[2] In that nearly all of the members of the Joint Committee on Atomic Energy were co-sponsors of the Hosmer Bill and because it was commented upon favorably both by Joint Committee members and by the AEC itself, it is expected that a similar bill will be introduced in the Ninety-Third Congress.

There are some differences between the role that the AEC plays in R&D Plowshare activities and the role that it is expected to play in commercial Plowshare activities. In Project Rulison, roughly ninety percent

of the work and cost load of the project was borne by the industry sponsors, and the remainder was borne by the AEC; similar apportionment of costs is expected to hold for future R&D shots. Nevertheless, R&D projects are essentially joint ventures of the industry sponsor and the AEC in which the AEC plays the dominant role in determining project goals and design from the time when the general project concept is first suggested by the industry sponsor. AEC expertise is thus employed directly and extensively to ensure optimum scientific or technological benefit as well as an acceptable degree of safety. In the commercial phase, according to present thinking, industry will be expected to bear the full cost. Furthermore, partly because of the number of projects anticipated and partly to allow for greater industrial choice and initiative, it is expected that the AEC will be less directly involved in project design and will merely offer advice, review, and approval of the industry plans to assure public safety before providing the nuclear device.

In other respects, however, the role of the AEC in R&D and commercial Plowshare projects will be similar. All nuclear devices will remain at all times under the possession and control of the AEC. Article I of the Treaty on the Non-Proliferation of Nuclear Weapons, to which the United States is a party, prohibits the United States from transferring control over nuclear explosive devices "to any recipient whatsoever."[3] In R&D Plowshare projects, the actual handling, emplacing, and detonating of nuclear explosive devices is done by AEC "contractors" -- companies other than the industry sponsors, operating on a cost-plus basis on behalf of the AEC under tight security and other government controls. A similar arrangement is contemplated for the commercial Plowshare phase: emplacement and detonation of nuclear devices will be performed by the AEC through its "contractors," as a service offered to industrial "users" for a fee. During the present R&D phase of Plowshare, the regulatory machine of the AEC is not involved in the planning and carrying out of Plowshare projects. Instead, because the nuclear devices remain at all times in the possession and under the control of the AEC itself, through its contractors, Plowshare projects are considered "operational functions" of the AEC. This means that they are administered by the officials responsible for the

material and are promotional as distinguished from the regulatory activities of the AEC. The precise arrangements that will control for the commercial phase of Plowshare have not yet been finally determined; it seems likely at this point, however, that the same arrangements that have governed thus far in the R&D phase will continue for both R&D and commercial Plowshare in the future. This is the assumption upon which the published memorandum of the AEC General Counsel's Office on "State and Local Regulation Affecting Performance of Commercial Plowshare Projects"[4] was based, and it is the assumption upon which the discussion of state powers herein is based. While it is assumed, therefore, that the operational rather than the regulatory branch of the AEC will be involved in the planning and carrying out of Plowshare projects themselves, the regulatory branch will surely be involved with respect to the hazards associated with the products and byproducts of Plowshare technology application.

State Versus Federal Powers

Confident of its ability to adequately provide for the health and safety of citizens and the environment and equally confident of the benefits expected to be derived from the various Plowshare applications, the AEC views the constitutionally permissible role of State government in Plowshare policy to be subordinate and relatively small. Although encouraging States to assume certain regulatory duties and costs and although generally willing to consult with state officials on matters of their concern, the AEC maintains that it alone will ultimately decide conditions under which Plowshare detonations will take place. The AEC's position as to R&D Plowshare was made clear by the then General Counsel during the hearings on the Hosmer Bill in May 1969. Moreover, a staff memorandum issued by the Office of the AEC General Counsel in November 1969 concluded that States would be powerless to impose any direct or indirect restraints or controls specifically upon Plowshare activities even in the anticipated commercial phase. Of course, it is to be expected that a variety of State regulations will apply to Plowshare activities just as they apply to other industrial activities; for example, zoning laws, fencing laws, mining laws, and highway regulations. Even as to these, however, the AEC advised the Joint Committee on Atomic Energy on July 11, 1969[4] that

> "In our judgment, the extent to which the state and local governments would have the authority to impose such regulatory controls would be limited by the statutory responsibility of AEC for the conduct of the nuclear explosions . . . and by the need for the exercise of reason and restraint in establishing state and local controls that could potentially frustrate the accomplishment of the objectives of the Federal Plowshare Program . . ."

The AEC Office of General Counsel has thus taken the position that states are precluded by constitutional principles from playing any role in Plowshare policy except as permitted by the AEC. The constitutional arguments to the contrary discussed by Engdahl[5] cannot be fully elucidated here, but they deserve at least brief discussion.

The crux of the AEC General Counsel's constitutional opinion is that Plowshare, both in its R&D phase and in the projected commercial phase, is an activity of the federal government itself. The fact that the nuclear devices remain under the control of the AEC, through its contractors, rather than under the control or in the possession of the industrial sponsor or user, means, in the General Counsel's view, that the emplacement and detonation of Plowshare devices is a "federal function." In that several cases hold that a state cannot interfere with the federal government or its employees or contractors in the carrying out of valid "federal functions," the conclusion would seem to follow that states cannot interfere with Plowshare activities. But this argument may overlook an essential consititutional distinction that is ignored and obscured by the use of the extra-constitutional term, "federal function."

In making nuclear devices available for either R&D or commercial Plowshare applications, the federal government is using some of its enumerated powers -- primarily its power over federally owned property, the nuclear devices. In those instances where the site of a detonation is on federally owned land, the property power is being exercised by virtue of that land ownership as well as by virtue of ownership of the device. As is the case with many of the conditions attached to various federal grants and licenses, however, the objective of the Plowshare program is extraneous to the realm of constitutionally contemplated federal governmental concerns. Industrial development, maintenance or improvement of the supply of energy resources, advancement of scientific technology -- these are highly desirable

objectives which the federal government may validly promote by means of the exercise of its enumerated powers; but, they are not matters which are constitutionally committed to the federal government. Consequently, while the federal government may validly formulate federal policies on these matters and seek to effectuate those policies by means of its enumerated powers, there is no constitutional ground for objection if it should happen that state action interferes with or frustrates the implementation of those federal policies. Plowshare is a "federal function" only in the sense that it is an extra-constitutional function which happens to be performed by the federal government. The activities involved in the cases upon which the General Counsel relies were "federal functions" in a very different sense.

The presence of unresolved constitutional questions makes the task of deciding upon wise Plowshare policies for the states exceedingly difficult. It is certainly possible that wisdom might dictate the exercise of less power than the maximum which a state might constitutionally assert; but, it is equally possible that uncertainty about the constitutional limits of the states' power might discourage a state from asserting as much power as wisdom would suggest. Furthermore, until at least some of the constitutional questions are resolved, the task of designing badly needed state legislation to deal with Plowshare problems in a way that will pass muster under the Constitution is practically impossible. Consequently, it seems of paramount importance that judicial tests of the critical issues of state power be deliberately undertaken without further delay. Appropriate test cases cannot be manufactured, of course; but, where any policy disagreement arises, it may be to the advantage of all parties in the long run to press the issues for judicial resolution rather than to work out an extra-judicial compromise that would leave the critical questions of constitutional power still unresolved. Such a test case was undertaken with regard to the Rio Blanco project in May 1973, although the principal issue was not one of federal constitutional power (see p VIII-5). However, Judge Henry E. Santo ruled on May 10, 1973, that the State Court had jurisdiction of both persons and subject matter in the suit and that such jurisdiction was not voided by the "federal preemption doctrine." CER Geonuclear Corporation subsequently filed a notice of appeal for reconsideration of the jurisdictional issue.

VIII. THE POSSIBLE STATE ROLES

The states are naturally interested in the economic potential which commercial utilization of Plowshare technology appears to offer. Consequently, they are also interested in the R&D programs which are aimed at making the realization of that apparent potential commercially practicable. At the same time, the states must guarantee adequate protection of the health and safety of their citizens and adequate protection of the other amenities of the environment increasingly being recognized as essential to a desirable quality of life. Of course, neither the federal government nor the industrial participants in Plowshare activities are insensitive to public safety and environmental concerns; but, the states have a particularly strong interest in and responsibility for these matters according to American law and tradition. Determining appropriate policies to be pursued by states with respect to Plowshare is complicated, however, by the fact that the direct operational involvement of the federal government introduces unusual and intricate constitutional questions with regard to state governmental power, as pointed out in Section VII.

Benefit-Cost Analyses

An important role that state governments must play with regard to Plowshare projects is that of evaluating benefits against costs and determining whether a particular Plowshare activity should proceed. Certain benefits and certain costs will have been weighed by the industrial sponsor or user before a particular project is proposed. The AEC will also weigh various costs and benefits before agreeing to participate in the project, for example, the demand which a project would place on limited supplies of special nuclear material. The tentative procedures for commercial Plowshare applications outlined to the Joint Committee on Atomic Energy during the 1969 hearings on the Hosmer Bill made no significant provision for assessment of public benefits to be derived from Plowshare proposals nor of alternative means for achieving the same industrial goals. The subsequently enacted National Environmental Policy Act requires that these factors be taken into account in any commercial Plowshare decision by the AEC. There is no reason, however, why any state should be precluded from making its

own assessment of certain benefits independently of the AEC. For example, a state might judge the benefit to be derived by one industry insufficient to outweigh the cost to another industry potentially more important to the economy of that state. Or a state might consider costs such as those associated with rapid industrialization of a region of the state, including impact on communities, government services, and environment, to outweigh the benefit to be derived from particular Plowshare activities. These considerations emphasize the need for a definite state role in the evaluation of benefits and costs in the light of specific state interests.

Assurance of Health and Safety

State governments are necessarily concerned with the present and prospective utilization of Plowshare technology because of potential seismic and radiation hazards (described in Section V). One role that state governments must accept, therefore, is that of minimizing the risk of damage or the degree of damage to the public. This role involves review of project design and of proposed procedures for eliminating or minimizing damaging seismic motion and radioactive venting at the time of detonation as well as later radioactive leakage or seepage and eventual ground water contamination. This role also includes the establishment of standards of acceptable levels of radioactive contamination in the products of Plowshare activities. It also involves the design or approval of acceptably safe methods for disposing of radioactive byproducts.

Both in the R&D phase and in the prospective commercial phase of Plowshare, the federal government oversees project and device design, site studies, and radioactive waste disposal. However, a state may also wish to oversee these activities and to enforce more stringent safeguards or to require more thorough preparatory studies. Although many of the factors upon which decisions concerning Plowshare projects must be based are highly technical, many states have access to the expertise required to make such decisions except in areas involving national security. Furthermore, many of the decisions rest ultimately upon judgement, and it might be considered preferable that they not be made by technical experts alone. Consequently, the fact that the AEC oversees the matters of preparatory studies and safeguards does not necessarily mean that the states should bypass the same role.

The federal government presumably will undertake to establish standards of acceptable levels of radioactivity in the products of Plowshare activities before any such products are distributed to the public. The responsibility for preparing such standards rests with the federal Environment Protection Agency (EPA). Formerly, the responsibility for establishing federal radiation standards for various applications rested with the AEC alone, and the AEC had maintained that federal jurisdiction over the whole field of radiation standards dealt with by federal law was preemptive of state power. But there is no real support for a claim quite that broad. The Supreme Court's 1972 decision in Minnesota v. Northern States Power Co. establishes federal preemption of state radiation standards with regard to navigable waters and ambient air, both of which are aspects of interstate commerce in the constitutional sense. Where Plowshare products enter interstate commerce, the standards-setting role of the states may also be preempted by interstate commerce jurisdiction. However, where interstate commerce is not involved, the standards-setting power of the states is not impugned by the Northern States Power decision or any other case. Thus, for example with regard to ground water, there is no authority for treating federal standards for acceptable levels of contamination as precluding more stringent state ground water standards or precluding the use of those standards as a basis for imposing state requirements concerning project design, site studies, and safeguards. And it may be permissible for a state to establish standards with respect to any Plowshare products not affected by interstate commerce.

Public health and safety were the main issues in the first court challenge to a Plowshare project in March 1970.[1] The plaintiffs charged that the flaring of natural gas during Rulison production tests would endanger the life, health and property of persons in the vicinity. After reviewing the evidence presented, Judge Alfred A. Arraj of the U.S. District Court in Denver ruled in favor of the defendants.

> "Our findings and conclusions on the factual issues show that this phase of the Rulison project and its flaring phase do not present a threat to health and safety. They show that the AEC has planned its activities and is carrying them out with all due regard to the health and safety of the public. They show that

the radiation dose from the flaring will be within standards of the AEC and other radiation protection institutions. They show that in the event of an accident which creates a danger of an excessive exposure, plans will be implemented to limit exposure to the established guidelines. Thus, plaintiffs have failed to show the probability of irreparable damage if the flaring is not enjoined, and have failed to establish a right to the specific injunctive relief sought."

In summary, if a significant role for the states in setting such standards or in approving project plans is considered to be desirable, the interested states may wish to secure such a role by advocating these provisions in new federal legislation authorizing the commercial phase of Plowshare.

Inspection and Enforcement

Another role which state governments should play is that of enforcement of procedures and standards related to health and safety. Areas of enforcement include (1) those involving proposed procedures for eliminating or minimizing damaging seismic motion and radioactive venting, (2) those for preventing radioactive leakage or seepage and ground water contamination, and (3) those involving standards of acceptable radioactive contamination and methods for disposing of radioactive wastes.

A state which chose to establish its own radioactive contamination standards for Plowshare activities (to the extent that is permissible) would also have to establish its own inspection and enforcement machinery. Inspection and testing to enforce compliance with federal standards for radioactive contamination will be performed by the federal government in those states which have not entered into agreements with the AEC under section 274 of the Atomic Energy Act.[2] In "agreement states," this function may be performed by state officials, but ordinarily at state expense. Agreement states also have the power to regulate through licenses the possession of byproduct radioactivity by industry. If such a state considers the procedures in a Plowshare project to be inadequate, it might enforce control through this licensing power.

Under a statute enacted in Colorado in 1970 after the Rulison experiment, it is required that, before detonation, a Plowshare project must be approved by the state's Water Pollution Control Commission.[3] The Commission is to approve the project, with or without qualifications, only if it finds that the detonation will create no threat of ground water contamination. Claiming that the Commission had not conducted an adequate investigation as required by the statute, and that it made inadequate findings to support the issuance of the Rio Blanco permit, the Citizens for Colorado's Future, et al., filed a suit against the Colorado Water Pollution Control Commission, CER, et al.[4] Judge Henry E. Santo ruled on May 14, 1973, however, in favor of the defendants on all points of the suit.

Tort Rules and Damage Claims

However many safeguards are exercised in Plowshare activities, the risk of damage to health and property remains. This possibility is one of the most important with which the states must deal. Courts in some states might apply rules of strict liability or absolute liability, without regard to fault; others may require proof of fault. Various defenses might or might not be allowed. Limitations of actions and measure of damage fairly responsive to the peculiar characteristics of Plowshare risks might or might not be judicially formulated when cases actually arise. One major difficulty with leaving the tort problems to be resolved some time in the future, after injuries have occurred, is that it makes it impossible to determine in advance, and make reasonable provision for satisfying, the kind of liabilities that may arise. Furthermore, the machinery of private litigation may be less desirable for dealing with such injuries than some administrative claims machinery.

Uniformity among the several states in the treatment of Plowshare damage claims may be desirable; however, federal power may supersede the tort rules of the states. Possible methods of redress for Plowshare-caused personal injuries and property damage, which would require legislation, have been investigated.[3,5,6] In one of these the state would require an industrial sponsor to provide an escrow account or post a bond equal to the upper limits of the potential seismic damage and establish an

independent arbitration committee to handle claim disputes. In another approach a negotiated permit fee is proposed as a means of indirectly compensating individuals who suffer damages from ground motion. Other approaches, through uniform state legislation or interstate compact among the states, might be explored. But, whether by a federal or interstate system or by independent state action, the inadequacies and uncertainties of ordinary tort law for dealing with possible Plowshare-caused injuries and damage demand legislative attention.

Assuring Compensation for Loss

Another role which state government must play is that of assuring that sufficient resources be available to satisfy all legitimate and sufficiently established claims. This probably involves compulsory insurance and governmental indemnity to underwrite potentially disastrous losses.

The federal government provides indemnification with respect to nuclear reactors under the Price-Anderson provisions of the Atomic Energy Act. It is widely assumed that the same provisions afford similar protection with regard to R&D Plowshare, and the Hosmer Bill contains language intended to extend that protection to commercial Plowshare. However, for several reasons, it is highly doubtful that the Price-Anderson provisions do provide adequate protection (or even any protection at all) in the Plowshare context, either as they now stand or as modified by the most recent Hosmer Bill.

The Price-Anderson Act empowered the AEC to make funds available for a portion of the damages suffered by the public from nuclear incidents and to limit the liability of persons for such loss (such as contractors or licensed promotors). A "nuclear incident" was defined as "any occurrence within the United States causing bodily injury, sickness, disease or death, or loss of or damage to property, or for loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of sources, special nuclear, or byproduct material."[2] The same concepts would apply to nuclear incidents of Plowshare but with some reservations: (1) the definition limits nuclear incidents only to

occurrences within the U.S., and thus excludes possible Plowshare activities abroad, (2) seismic risks are not explicitly included, and (3) the definition restricts itself to specific damages to the exclusion of other loss consequences such as mental suffering or decreases in property values.

The act required the licensee (AEC's contractor) to carry the maximum available insurance or to have the financial capacity to pay that amount in claims. At the same time, the licensee's extent of liability is limited to the insurance amount required and available from private insurance which is currently $100 million. The AEC will indemnify and hold harmless the licensee and other persons indemnified from public liability up to a limit which together with private insurance does not exceed $560 million. To encourage the development of Plowshare industry and to protect the public, the same concepts of maximum liability limit and insurance indemnity arrangement should also apply to Plowshare activities.

Before financial requirements similar to those of licensees of nuclear reactors can be stipulated, the American insurance industry must be willing to insure the risk. Because there are substantial differences in the risks associated with nuclear reactors and nuclear detonations, the insurance industry must draft a new policy form. It appears that a specific insurance policy form for industrial Plowshare will be available in 1973.[7] The commercial insurance obtained by CER Geonuclear for the Rio Blanco project, however, covered seismic damage only and not radiation injuries.[8]

In addition to general provisions for compensation, states should review their workmen's compensation laws to assure adequate and prompt indemnity of work injuries in Plowshare projects, particularly from cumulative low-level radiation exposures. Lack of effective procedures of early discovery, proof, and compensation for such industrial hazards would place the financial consequences entirely on the state.

In summary, any state in which either R&D or commercial Plowshare activity is planned would be well advised to assure that adequate financial capacity exists to satisfy valid damage claims before permitting the Plowshare activity to proceed.

Recommendations for Federal Legislation

In that the necessary authorizing federal legislation for commercial Plowshare has not yet been enacted, only suggestions for appropriate state action may be made at this point.

1. Since the record of AEC support for such legislation seems sufficient to constitute a "proposal for legislation" within the meaning of the National Environmental Policy Act (NEPA), it would seem that any new commercial Plowshare bill must be accompanied by an impact statement detailing the predictable environmental effects and alternatives. It would be appropriate for the states to insist upon full and faithful compliance with NEPA by the AEC in this instance.

2. The states would be wise to persuade Congress to draft legislation authorizing commercial Plowshare applications to assure the states the appropriate role in the regulation of this technology and to provide the framework for appropriate intergovernmental cooperation. Much is to be gained by working out an acceptable allocation and integration of state and federal responsibilities in advance and specifying this arrangement in any commercial Plowshare legislation that Congress might enact.

IX. STATE INSTITUTIONAL IMPLICATIONS

It is not possible to determine the optimum institutional structure for state regulation of Plowshare, because the permissible bounds of policy control by the state are unclear. The several suggestions offered here presume that a maximum level of state policy control in Plowshare matters will be afforded, whether by constitutional principle or by appropriate federal statutory provisions.

The role of establishing and policing appropriate standards for protection of the public from the radiological hazards associated with the products and byproducts of Plowshare technology is one that can best be performed by a permanent state administrative agency. Presumably, adequate expertise for these tasks already resides in each state in the State Department of Public Health or its equivalent. Each of the states in which Plowshare projects or products may appear should make whatever revisions, if any, may be needed in its statutes to enable the Health Department to make and enforce the necessary standards in this area. Where staffing is inadequate to perform such expanded functions, the necessary staff should of course be added. In preparing standards of radiological safety, a state agency might conform to the federal standards; however, a state may wish to impose more stringent requirements. In that not every State Health Department or its equivalent can carry on its own continuing research program to test and update its standards, the Department should cultivate contacts with institutions and persons who may be independently engaged in such research. It would be useful for the states to have the benefit of a clearinghouse for information about such research, independent of and in addition to the information made available through the AEC. For the western states, the Western Interstate Nuclear Board might perform this function.

The institutional implications of a state role in determining whether or under what conditions a Plowshare project is to take place are based in part on considerations of radiological hazards associated with the detonation of a nuclear device as well as the use and disposition of products and byproducts. For this reason, the State Health Department, or its

equivalent must again be involved in the determination. Other factors to be considered are the economic consequences of resource development, effects upon competing resource industries, ecological consequences, and the alternative means for supplying resource needs. Because of the broad scope of these factors, no single governmental agency can be expected to have the expertise required for making all of these Plowshare decisions.

As pointed out on page VIII-5, Plowshare projects in Colorado must be approved by the state's Water Pollution Control Commission. The Commission is to approve the project only if it finds not only that the detonation will create no threat of ground water contamination, but also that it is "justified by public need." If this requirement is applied as it seems to be intended, it opens the whole question of weighing benefits against possible short-range and long-range impacts that a project might have upon resources, health, population, the state's economy, etc. The expertise of a water pollution control commission does not necessarily qualify such a body to pass judgment upon these questions, nor could any other single board or agency be appropriately charged with such a broad task. It seems wiser to place ultimate responsibility on behalf of the state to approve or disapprove Plowshare detonations in the office of the governor of the state. Only the governor is in a position to draw upon the expertise of several state departments as well as outside consultants and to give full consideration to all the diverse factors that should be brought to bear upon such a decision. Furthermore, the direct political accountability of the governor should help ensure not only comprehensive but responsible consideration of the issues that may be involved. This centralization of state decision would seem to have distinct advantages over a proliferation of administrative hurdles to be confronted one after another by the sponsors of a Plowshare project.

Such a pattern of gubernatorial oversight and power of veto over Plowshare detonations have evolved in Colorado. In 1971, Governor John Love claimed to have been granted a veto power over further non-defense related nuclear explosions in Colorado by Dr. Glenn Seabory, Chairman of the USAEC. However, it is not all certain that such a power of veto would be sustained if subjected to judicial challenge. It might be argued that the

"agreement" with the AEC upon which the governor bases his veto power was restricted to the single Rio Blanco project. Any state to which the gubernatorial role now being asserted in Colorado seems desirable, therefore, should firmly secure that role by enabling legislation. Specifications might be added to provide for the governor's utilization of a committee of advisors, representing at least the appropriate state agencies, but it would be inadvisable to include restrictive detail that might interfere with opportunities for institutional flexibility.

X. PUBLIC PARTICIPATION

A phenomenon of recent times is the strong public awareness and concern with regard to the environment and the increasing public participation in major governmental decisions. Citizen groups have organized to fight pollution and other public nuisances associated with industrial development. Public reaction to Plowshare technology now seems to indicate a change from non-concern in 1967 when the Gasbuggy shot was fired to the organized opposition to projects Rulison and Rio Blanco. Indeed, the industrial Plowshare program, especially nuclear stimulation of natural gas, has received considerable public attention and can be expected to receive very careful scrutiny in the future.

Representative Craig Hosmer recognized the growing importance of the public relations aspects of Plowshare. He pointed out that despite the fact that Plowshare projects are generally conducted in very remote and unpopulated areas, it will still be necessary to carry out an active public relations campaign to demonstrate the benefits to be achieved. He noted the experience with project Ketch, where opposition from the public and state officials caused the withdrawal of the application.[1]

Public objections to the proposed gas stimulation projects seem to be most directly related to the ecological considerations. Much of the opposition has been from the Colorado Committee for Environmental Information, a group of lawyers, chemists, geologists, physicists, etc., formed to supply citizens with the facts for intelligent protest. They have expressed concern about radioactive pollution and seismic damage that may result from nuclear detonations, and they also question the economic benefits to be gained from nuclear stimulation projects.

There is public concern over the possible conflict of interest in the Atomic Energy Commission in that the AEC promotes the nuclear industry and at the same time is in charge of public safety and environmental considerations. Metzger hits hard on this issue: "The AEC must be allowed to regulate itself no longer -- complete and factual information concerning its plans must be made freely available to the public. Benefit-risk analysis can no longer be decided in secret by a technological elite -- they must

be decided by all."[2] The formation of the Environmental Protection Agency (EPA) to protect the nation's environment has been one step in the right direction, and the division of the AEC slated under the new federal energy structure might well obviate the original public concern.

Public Information

Public information must precede public participation. The public must be given all facts which bear relevance to a specific Plowshare project, and they must be made aware of the social and economic benefits, possible risks, and public and environmental protection measures. Representative Hosmer emphasized best this importance to Plowshare development: "Given a clear and accurate picture of the potential benefits and the high level of scientific precautions being taken, the public will not be unduly alarmed about possible hazards. For its part, industry must try to do its homework well and promptly respond to public inquiry and hesitation. When this is done, this nation and the world will be able to glean the vast benefits available by applying this new engineering tool to man's advantage instead of his destruction."[1]

The public is constantly beset by extreme differences of opinions -- from that of the zealous conservationist to that of the insensitive technocrat. When only the two extreme viewpoints are made available, the public has trouble reconciling the differing views. Because public reaction presents a substantial constraint to further development of a Plowshare industry, it is important that factual information be impartially presented to the public for evaluation.

In a survey conducted by the University of Colorado (December 1967), it was found that a significant portion of the respondents did not appear to have all the facts about benefit-cost (including risks) of Rio Blanco.[3] While 75.9% of the respondents felt that the project would benefit the Meeker area economically, 13.1% believed it was intended to develop an oil shale industry and only 38.7% knew that 100 or more explosions would be required to develop the entire Rio Blanco field. Clearly, the Colorado study, like other studies in similar areas, indicated that the attitudes of respondents were based on very limited and frequently faulty information

and belief. This is very difficult to understand because the CER Geonuclear Corporation conducted an extensive series of local meetings and presentations relative to Rio Blanco in Colorado. See Appendix D.

State government has direct interest in and responsibility for disclosure of factual information to its citizens. In a meeting between WINB's representatives and Governor Love of Colorado, the Governor expressed his concern over the problem of obtaining what he termed "in-depth information" on Rio Blanco. He was also sensitive to the fact that since so many of the briefings were given by the promoters, some information would be biased and that fact would be brought out by the opponents, thereby adding embarrassment and confusion and detracting from the credibility of the project. In a similar meeting, Governor Hathaway of Wyoming indicated that the main problem with Project Wagon Wheel is that El Paso Natural Gas has not sold the local people on the idea properly. A two-year lapse occurred between the first public briefing and the next one; during this time, the people developed a solid wall of resistance. He felt that continued public information and input by the sponsors would have alleviated most of the resistance. Governor Hathaway indicated that El Paso and the AEC were not specific enough regarding the number of nuclear detonations required for full field development.

Methods for Obtaining Public Participation

Granted that public participation in decisions over Plowshare projects is desirable, the issue is how to get the public to constructively participate in these decisions. For this purpose, six means for public participation are briefly discussed as follows.[4]

Public Hearings: Public hearings have been frequently used for the dissemination of information as well as the exchange of different views over new Plowshare projects. However, the effectiveness of this approach to public participation is limited for several reasons: (1) participation in public hearings is restricted by procedural requirements such as the submission of several copies of the participant's statements many days before the hearings and by the time and cost required for the local people to travel to the place of the hearings, (2) there is no assurance that

participants in the hearings represent various interest groups, especially the residents of the local community most affected by the project, (3) the hearings are usually dominated by scientists and lawyers where discussions become too technical for the populace to follow, (4) some of the participants in the hearings do not have all the factual information pertinent to the issues, and (5) the hearings are usually resolved without specific decisions reflecting a majority opinion.

Public Meetings: In contrast to public hearings, less formal public meetings can provide a vehicle for interchange of information and discussion. At the request of various interest or social groups, the industrial sponsor will explain the project and its advantages and answer questions. The CER Geonuclear Corporation held over thirty such meetings in anticipation of Rio Blanco (Appendix D).

Undoubtedly, these meetings are effective in providing first-hand information about the project to those who are interested enough to attend. On the other hand, the effectiveness of this approach as a public participation medium is limited by the following: (1) there is no assurance that all groups, particularly those residing close to the project site, will be represented, (2) such meetings are usually cordial and superficial in the sense that technical or embarrassing issues are frequently avoided, (3) no actual measurement of public acceptance or rejection of the project is made, and (4) there is no assurance that points of view different from those of the industrial sponsor will be adequately presented.

Opinion Polls: With the exception of the University of Colorado survey referred to above, not many polls of public attitudes toward Plowshare projects have been recorded. On the other hand, several public polls have been taken in communities considered for siting power plants and industrial projects. Opinion polls appear to offer a more effective approach for measuring public attitudes toward new projects than public hearings for several reasons: (1) the local community most affected by the project is given a better chance to present its attitudes directly, (2) the statistical analysis of the results usually provides a quantitative measurement of the majority and minority opinions, (3) opinion polls would reveal more data than a public hearing because the responses could be classified according to location,

occupation, level of knowledge, etc., (4) it encourages more serious public interest about the benefit-cost aspects of the new project and evokes more phychological satisfaction on the part of the participants, (5) the public usually has more confidence in the outcome of the poll and is more inclined to accept the wishes of the majority opinion, and (6) opinion polls usually give more results at a relatively lower cost.

On the other hand, the effectiveness of opinion polls is constrained by the size and design of the sample, the level of public knowledge at the time of the poll, and the type of questions asked. Opinion polls are probably a less efficient media for dissemination of public information as with public meetings but are indeed a better approach to public participation than public hearings.

Public Referendum: Some might argue that the best approach to obtaining public participation would be to contact the public directly through a referendum. Prior to the referendum, the mass media, political parties and various interest groups should debate the issues so that the public could get a clear picture of the benefits and risks involved. The final decision would be determined by a public majority vote through a referendum.

Although public referendums have frequently been used to resolve highly controversial issues, the use of this approach for Plowshare projects would involve several aspects that should be considered: (1) considerable time and effort are required to conduct a public referendum, (2) decisions must be made as to whether the referendum would be conducted for each project, or for several projects, (3) the scope of the referendum (state, county, or local community) must be determined, and (4) the relative importance of each area of response must be assessed.

Legislative Prodecures: Although most state functions with respect to reviewing and supervising specific Plowshare projects lie with the executive machinery, the state legislature has the power to enact appropriate statutes to regulate such activities. The governor as the chief executive in a given state might consider that a highly controversial Plowshare project should be approved by the state legislature. Consequently, the public through their legislative representatives would get a chance to investigate benefits and costs of a given project and could voice approval or disapproval.

Interest groups could also reflect their views and attitudes through their representatives. By carrying out the recommendations of the legislature, the governor would have given the public a chance to share in the decision-making.

On the other hand, this approach to public participation might have several drawbacks: (1) legislative endorsement might be required for each detonation, (2) considerable time and effort would be required to fully investigate a Plowshare project, and (3) credibility of the representatives may be clouded by political inclinations or by the influence of various interest groups.

Governor's Advisory Committee: Another method of obtaining public participation involves most of those discussed above: the use of a governor-appointed advisory committee. Such a committee reflects public participation by the diversity of its membership which could include representatives from concerned groups. Furthermore, the committee could conduct opinion polls, public meetings, and public hearings, and thereby assure the gathering and dissemination of information. Moreover, the committee could be charged with the responsibility for obtaining an objective benefit-cost analysis of the project.

Prior to the Rio Blanco experiment, Colorado's Governor Love appointed a special advisory committee to evaluate the proposed experiment in terms of its likely risks and benefits to the State of Colorado. The committee originally consisted of 18 members picked to represent a broad cross-section of interests and skills. Though there were some changes during the course of the Committee's life, new appointments maintained the balance between local and State personnel, environmental and industrial interests, and broad professional capabilities. As originally constituted, there were 3 state government representatives, 3 local residents (1 of whom was a County Commissioner), 5 industrial representatives, 4 university professors, and 3 representatives of environmental groups.

The Committee first met in June of 1971 with Governor Love. He requested the Committee to evaluate the proposed Rio Blanco experiment, particularly as to the safety of the people in the area and any hazards to the environment. He also expressed great concern as to whether such an

experiment, later followed by full field stimulation, would endanger the development of the vast oil shale reserves in the Piceance Basin. The Committee, however, was asked only to consider a recommendation for the single Rio Blanco experiment. The Committee held a number of meetings at which they were briefed by both proponents and opponents, and they listened to the questions and concerns of local residents as well as persons from other parts of Colorado. After considerable discussion, the Committee by majority vote agreed to recommend that Governor Love approve the Rio Blanco experiment but with limiting stipulations.

Only Governor Love knows whether the Committee and its recommendation were of value to him. Certainly, all of the Committee members came out of the experience better informed and with a better understanding of other points of view. Though there were many differences of opinions, these were expressed openly and without rancor, and discussions were honest and candid. There were problems that the Committee could not resolve in its own mind. For instance, the Committee heard experts state that nuclear stimulation of natural gas would not affect the development of the oil shale resources and equally qualified experts say that it would be ruined.

In summary, all of the above means of public participation in state decisions over Plowshare projects have merits and demerits. The best approach would depend on many factors, mainly, the time and resources available for this purpose; the nature of the project; and the political, economic, and sociological conditions of the particular state.

XI. BENEFIT - COST CONSIDERATIONS

In industrial Plowshare projects, there will be differing benefit-cost ratios among different public segments - local, state, and nation. The benefit-cost calculus should include economic, sociological, and environmental factors. Figure XI-1 shows a benefit-cost matrix which reflects these parameters. Such a matrix would provide guidelines for the detailed analyses to be performed in each area of consideration. Such analysis can only be done for a specific industrial Plowshare project in a given community.

	Local	State	Nation
Economic			
Sociological			
Environmental			

Figure XI-1. Benefit-Cost Matrix

Obviously, the residents in the vicinity of the detonation site are more vulnerable to the negative aspects (costs), such as risks, environmental insult, inconvenience, social cost, etc., than those who live farther away. Meanwhile, the economic gains in terms of employment opportunities and reduced taxes are not at all certain. Thus the perceived benefit-cost ratio for the populace in a state may be greater than that of the local people but perhaps less than that of the nation as a whole. Otway, et al., in a recent natural gas stimulation study, estimates that the benefit-cost ratio for individuals close to the Plowshare shite may be as low as 6:1 while the net societal benefits would be 30 to 50:1 for the population in general.[1] They included such benefits to the local populace as increased employment and tax revenues and such risks and inconveniences as radiation exposures, ground motion, evacuation costs, and workmen's risk.

In the absence of reliable models of benefit-cost analysis, subjective judgment must play a major role. Probably, the best approach is to give the local community factual information about the Plowshare project and let

them determine their perceived costs (risk) and benefits. Very often, the perceived benefits and costs by people in a community are different from their actual benefits and costs. However, the above studies can have very significant consequences: (1) factual information about all benefits and costs including risk from a given project will be prepared and delivered to the people concerned, (2) the benefits to the local community can then be increased and the costs or risks minimized to increase the benefit-cost ratio, (3) efforts can also be directed towards increasing public participation in the decisions over Plowshare projects and thereby increase the community level of acceptance.

Certain benefits and costs will have been weighted by the industrial sponsor before a particular project is undertaken. Beyond that industrial assessment, the AEC will weigh various costs and benefits before agreeing to participate or to supply and detonate a nuclear device. This AEC assessment would take into account, for example, the demand which a project would place on limited supplies of special nuclear material. However, the tentative procedures for commercial Plowshare applications outlined to the Joint Committee on Atomic Energy during the 1969 hearings on the Hosmer Bill made no significant provision for assessment of the relative public benefits to be derived from competing commercial Plowshare proposals nor for considering a Plowshare application in light of other means of achieving the same industrial goals nor for weighing the benefit to be derived by the public against the cost to the public in terms of health and safety risk. It would seem that the subsequently enacted National Environment Policy Act now requires that at least several of these factors be taken into account in any commercial Plowshare decision made by the AEC. There is no reason, however, why a state should be precluded from making its own assessment of benefits and risks independently of the AEC. A state, for example, might judge the potential benefit to its own citizens insufficient to justify the Plowshare-associated health and safety risks to its own citizens, even though those risks be within federally established limits and be found acceptable in the judgment of the AEC when balanced against benefits to persons and interests beyond the state. Or, a state might judge the benefit to be derived by one industry insufficient to

outweigh the cost to another industry potentially more important to the economy of that state. Or, a state might consider costs such as those associated with rapid industrialization of a region of the state, including short and long term economic impact on communities, government services, and environment, to outweigh the benefit to be derived from particular Plowshare activities.

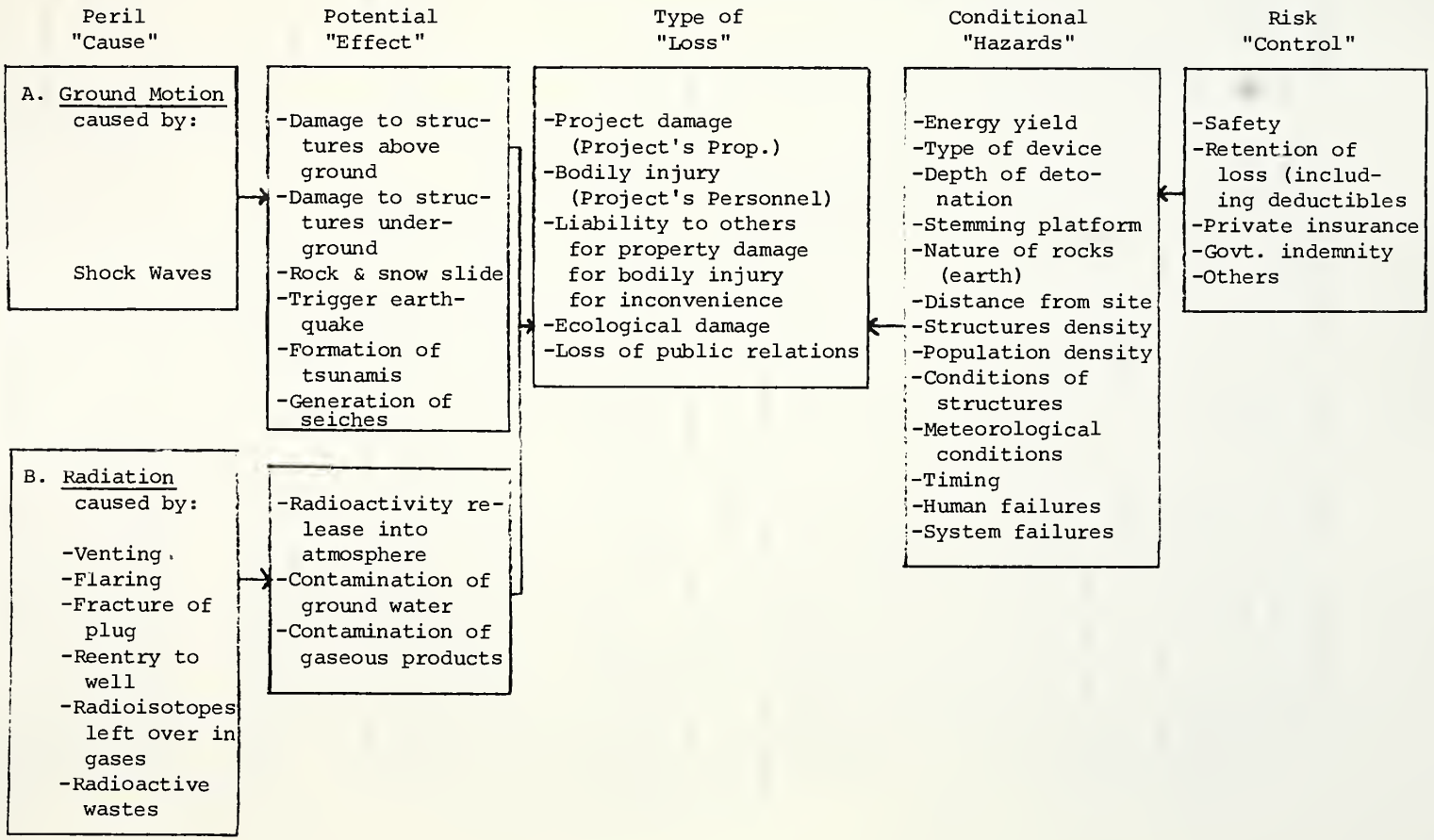
Decisions based upon these latter sorts of benefit-cost considerations should be made at the state level by officials who are capable of examining the necessary factors thoroughly and objectively but who are also held politically responsible for their decisions. Legislation providing for such official state review and approval of industrial Plowshare activities should make possible judicial enforcement of the requirement that all pertinent information be submitted to the decision-making officials; however, the final decision for accepting or rejecting a Plowshare project should remain with those state officials and not with any court. Furthermore, provision should be made to prevent unnecessary reconsideration and delay once a well-considered judgment approving a particular Plowshare activity has been made.

Risk Analysis

An essential requirement for any benefit-cost analysis of industrial Plowshare projects is that the quantification of risks be included as major cost factors. While benefits to be derived from an industrial project are normally easy to recognize and quantify, total costs, which must include economic, social, and environmental considerations, are not always as easy to identify and analyze. A brief analytical frame work of the two major Plowshare risks -- ground motion and radiation -- for the specific application to natural gas stimulation is illustrated in Figure XI-2.[2] Although lists such as this are useful in identifying all possible cost factors, the task of quantifying the losses in a consistent set of cost units is extremely difficult. In most cases, subjective evaluations of the relative cost of each type of loss may be necessary.

Figure XI-2

A FRAME WORK FOR RISK ANALYSIS
NUCLEAR STIMULATION OF GAS (2)



In an attempt to quantify radiation risk, Otway and Lohrding developed a model for estimating the risk from a Plowshare detonation, excluding natural gas projects.[3] In their model, the individual's risk and probability of death was found as a function of distance from a postulated radiation release. The total population risk in deaths was then found by integrating individual risk over the population density at distances from the detonation point. Their data were from underground Nevada Test Site nuclear experiments which may not be directly applicable to off-site, industrial Plowshare projects. They concluded, however, that the risk of dying from an off-site Plowshare experiment appears to be negligible.

Chauncy Starr suggested a model to measure an "acceptable risk/benefit trade-off."[4] He used as a basis for risk estimation the number of accidental deaths per person hour of exposure and the average benefit per person involved in terms of monetary value. He also differentiated between voluntary and involuntary involvement and proposed that the general acceptable level for risk with involuntary involvement such as the radiation risk associated with electric power generation is much lower than with voluntary activities such as hunting and general aviation. His conclusion, based on historical accident records, indicated that the "maximum level of public acceptance" for involuntary involvement is very near the risk level of disease for the entire U.S. population.

Several other investigators have employed a variety of techniques to make a monetary estimate of the deleterious effect per man-rem of whole body radiation exposure. These values have ranged from about $7/man-rem to $250/man-rem.[5] For a local community, however, such radiation costs can be misleading in the sense that actual cost could be deaths if one serious accident took place. Metzger opposes the extension of this scientific logic into the field of human sociology and psychology where human values are reduced to arithmetic parameters.[6]

Recent literature shows that research on the techniques of benefit-cost analysis is receiving considerable attention and that some progress has been made in providing this valuable and perhaps necessary tool for technology assessment. It is clear, however, that benefit-cost calculus is still in its very early stages of development, particularly with regard

to the establishment of a widely accepted consistent set of risk units for comparison with benefits which are usually described in terms of dollars. Although the models described above are not complete and have received criticism for a number of reasons, the quantification concepts used may be applicable, and studies such as this should eventually provide an acceptable basis for risk analysis. At this point, however, it is obvious that after all identifiable risks have been outlined for a potential industrial Plowshare project, as shown in Figure XI-2, subjective judgment must still play the major role in assessing their costs.

XII. SUMMARY

The WINB Plowshare Technology Assessment Project, the results of which are summarized in the foregoing chapters, was designed to develop information of potential value to state and local governments and the general public in evaluating, decision-making, and planning for the projected use of nuclear explosives technology in various commercial applications. Although an attempt has been made by the research team to make the results of this study generally applicable to a wide variety of Plowshare applications, it is the natural gas stimulation concept of Plowshare which has demanded the Board's attention during this study. The next phase of the Plowshare natural gas stimulation program is expected to be oriented toward "full field development" -- large-scale gas recovery involving perhaps hundreds of detonations over a number of years. Full field development poses a number of issues:

1. Economic
   a. Availability of "special nuclear materials" for Plowshare devices (SNM is expected to be in great demand for other uses such as nuclear-electric power)
   b. Contributions of Plowshare natural gas recovery to local, regional, and national economies
   c. Costs of development of wells and subsequent natural gas production as compared with other recovery techniques.

2. Environmental and Social
   a. Effects of ground motion caused by nuclear detonations
   b. Localized radiation emissions
   c. Degree of radiation contamination in natural gas distributed to consumers
   d. Effects on land-use, aesthetics, etc.

3. Government Regulation
   a. Degree of government regulation and surveillance
   b. Interagency and intergovernmental cooperation
   c. State versus federal powers.

4. Public Acceptance

   a. Appropriate methods of encouraging widespread public understanding of the technology and the issues involved

   b. Methods of fostering public participation in the decision-making and planning processes.

This study has not attempted to resolve these questions, but rather has sought to define the issues and to provide information believed to be needed by decision-making bodies in the state governments.

At the time of this report, with the possible exception of the Rio Blanco full field development, there appear to be no imminent Plowshare experiments or programs being planned in the western states. Nevertheless, this is the time for state action and state planning to commence. State legislatures have the responsibility of determining that appropriate statutory provisions are made for public health and safety, natural resource utilization and conservation, and economic development, relative to Plowshare applications. It is recommended that existing statutes concerning radiation control, radiological health, air and water pollution, and natural resources be reviewed as to their adequacy in regulating Plowshare projects. Those states which have not assumed from USAEC responsibility for regulating certain radioactive materials as provided for in Section 274 of the Atomic Energy Act ("Agreement state" program) should consider implementing by statute or agreement this program to provide a basis for at least a portion of the state's regulatory efforts concerning Plowshare.

It appears ill-advised at this time for states to enact moratoriums on Plowshare projects via statutes or referendums. Instead, it is suggested that statutes and administrative regulations provide for adequate resources and procedures for evaluating Plowshare projects and programs on their individual merits. The Conclusions and Recommendations, Section II, of this study should provide a helpful frame of reference for the formulation of these regulations and procedures. The Western Interstate Nuclear Board offers its capabilities and experience to state governments interested in planning and evaluating possible future Plowshare programs.

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APPENDIX A

ABBREVIATED PLOWSHARE CHRONOLOGY

Date	Event or Study
Nov. 26, 1956	Atomic Energy Commission approved in-house conference on peaceful uses of nuclear explosives.
Feb. 1957	First Plowshare Symposium held at LRL to discuss "Industrial Uses of Nuclear Explosives."
Jul. 1957	Lawrence Radiation Laboratory (LRL) Livermore, formally established Project Plowshare to investigate the non-military applications of nuclear weapons.
Oct. 1957	Corp of Engineers agreed to supply support services for Plowshare program.
Aug. 15, 1958	U.S. Geological Survey agreed to conduct support studies for Plowshare program.
Sept. 9, 1958	U.S. Bureau of Mines agreed to cooperate on Plowshare program.
Oct. 1958	U. S. began voluntary moratorium on all nuclear testing.
May 13-15, 1959	The Second Symposium on the Plowshare program was held in San Francisco, California, with 495 attendees.
Sept. 1961	The U.S. voluntary test moratorium of two years and 11 months duration was ended.
Dec. 10, 1961	Gnome - The first nuclear detonation executed under the Plowshare program. Yield - 3.1 kt. Depth of Burial - 1184 ft. Medium - salt Cavity Dimensions - radius 80 to 85 ft., height 60 to 80 feet. Site - near Carlsbad, New Mexico Objectives - 1. isotope recovery 2. neutron physics experiment 3. examination of heat recovery 4. seismic measurements 5. explosive development

Date	Event or Study
July 6, 1962	Sedan - Plowshare nuclear excavation experiment. Yield - 100 kt Depth of Burial - 653 ft. Medium - Alluvium Cratering Dimesions - Diameter 1,280 ft., depth 320 ft.; volume - 7.5 million cu. yards. Site - Nevada Test Site Objective - Study effects and phenomenology of cratering detonations in alluvium.
Oct. 1963	The Limited Test Ban Treaty was ratified by the President, with consent of the Senate. The treaty prohibits nuclear explosions in the atmosphere, in outer space and under water. It also prohibits any underground explosion "which causes radioactive debris to be present outside the territorial limits of the state under whose jurisdiction or control the explosion is conducted."
Apr. 21-23, 1964	The Third Plowshare Symposium, "Engineering with Nuclear Explosives" was held at the University of California, Davis, California.
May 1964	The U.S. Atomic Energy Commission released the following charges for Plowshare explosives for use by industry in conducting studies of economic and technical feasibility: 10 Kilotons - $350,000 2 Megatons - $600,000
Nov. 5, 1964	Handcar - Plowshare nuclear explosion experiment. Yield - 12 kt. Depth of Burial - 1,320 ft. Medium - dolomite (carbonate rock) Side - Nevada Test Site Chimney dimesions - radius 69 ft., height 233 ft. Objective - Study effects of nuclear explosives in carbonate rock.
Dec. 6, 1966	Project Dragon Trail - Joint natural gas stimulation experiment proposed by Continental Oil Company and CER Geonuclear - inactive as of May 1970. Proposed site - Rio Blanco County, Colorado.
Jan. 31, 1967	Gasbuggy contract signed by El Paso Natural Gas Company, the Department of the Interior, and the AEC.
Aug. 1967	Project Ketch - A joint feasibility study begun in 1965 was completed by the Columbia Gas System Service Corp., U.S. Bureau of Mines, Lawrence Radiation Laboratory, and the AEC to study uses of nuclear explosives to create underground natural gas storage reservoirs.

Date	Event or Study
Oct. 24, 1967	Project Bronco - A joint feasibility study begun in 1966 was completed by CER Geonuclear, representing some 20 oil companies, the Lawrence Radiation Laboratory, the U.S. Bureau of Mines and the AEC to study the use of nuclear explosions to fracture oil shale for subsequent recovery of oil by an in-situ retorting process. Necessary industry support to carry out the experiment has not yet been identified.
Oct. 25, 1967	Project Sloop - A joint feasibility study begun in 1965 by the Kennecott Copper Corporation, U. S. Bureau of Mines, Lawrence Radiation Laboratory, and the San Francisco Operations Office - AEC to consider the overall feasibility of using nuclear explosives for fracturing low grade copper ore bodies for subsequent recovery of copper by conventional in-situ leaching methods was completed.
Dec. 10, 1967	Project Gasbuggy - The first Plowshare joint government-industry nuclear experiment to test out an industrial application. Participants - El Paso Natural Gas Company, Department of Interior, Atomic Energy Commission. Technical Director - Lawrence Radiation Laboratory. Yield - 29 kt. Depth of Burial - 4,240 ft. Medium - Sandstone, gas bearing formation. Chimney height - 335 ft; radius - 80 ft. Site - San Juan Basin, New Mexico. Objective - To investigate the feasibility of using nuclear explosives to stimulate a low producing gas field.
Jan 24, 1968	Project Wagon Wheel - A detailed project definition was begun by the El Paso Natural Gas Company, U. S. Atomic Energy Commission, and the Department of the Interior to evaluate the potential of nuclear stimulation techniques in the Pinedale, Wyoming area.
May 1968	Aquarius Study - The Arizona AEC, the Department of the Interior, and the USAEC began a study of two potential applications of the use of nuclear explosions for water management purposes in Arizona.
July 1, 1968	Nonproliferation Treaty signed. Article V provides that potential benefits of peaceful applications of nuclear explosions will be made available to non-nuclear-weapon states party to the Treaty.

Date	Event or Study
Jan. 3, 1969	H.R. 477 introducted in the House by Representative Hosmer. Legistlation would authorize AEC to make peaceful nuclear explosion service available to domestic and foreign users for practical applications.
Mar. 26, 1969	Rulison contract signed by Austral Oil Company, CER Geonuclear Corporation, the Department of the Interior, and the AEC.
Jul. 30, 1969	WASP - The Wyoming Atomic Stimulation Project (WASP) composed of seven independent oil companies, the U.S. Atomic Energy Commission and the Department of the Interior began a detailed project definition of using nuclear explosions in the Pinedale, Wyoming area.
Sept. 10, 1969	Project Rulison - A joint government-industry gas stimulation experiment. Participants - Austral Oil Company, CER Geonuclear Corporation (program manager), Department of the Interior, Atomic Energy Commission. Technical Director - Los Alamos Scientific Laboratory. Yield - 40 kt. Depth of Burial - 8,430 ft. Medium - Sandstone, gas bearing formation. Chimney dimensions - height 270 ft.; radius 70 ft. Site - Garfield County, Colorado Objective - To investigate the feasibility of using nuclear explosives to stimulate a low producing gas field.
Jan. 14-16, 1970	Symposium on "Engineering with Nuclear Explosives," sponsored by the American Nuclear Society was held in Las Vegas, Nevada.
Mar. 16, 1970	The Rulison Court decision by the U.S. District Court for the District of Colorado (Judge Alfred A. Arraj) ruled that: the flaring phase of Project Rulison does not present a threat to public health and safety; the AEC has planned its activities and is carrying them out with all due regard for health and safety; and radiation dose from flaring will be within radiation standards.
May 6, 1970	Geothermal Study - The American Oil Shale Corporation and the U.S. Atomic Energy Commission began a joint study of the feasibility of using nuclear explosions to assist in generating power in geothermal areas. No potential sites have yet been proposed.

Date	Event or Study
Dec. 18, 1970	Project Rio Blanco - The feasibility study prepared by the industrial sponsor CER Geonuclear (using lands obtained under joint venture agreement with the Equity Oil Co.) was accepted as a basis for entering into joint project defini- activities with CER.
Feb. 1973	The Kennecott Copper Corporation and the U.S. Atomic Energy Commission announced that they had signed a contract to undertake jointly a program of investigation, study and evaluation of in-place copper leaching technology that could be applied in an ore body fractured by a nuclear detonation. The process to be studied would involve the possibility of fracturing a deeply buried low grade copper bearing deposit with a nuclear explosive and then percolating an oxidizing leach fluid through the fractured rock. The leach would then be pumped to the surface where the copper would be extracted. In 1967 a similar project called Sloop was focused on an ore body at Safford, which was above the water table. The current study is broader in scope; it will incorporate data on several ore bodies which are below the water table. No field work is contemplated, but a concept will be developed for a surface extraction plant and for other facilities needed for processing copper leach solutions. The study is expected to be completed in early 1974.
Apr. 12, 1973	Rio Blanco contract signed by CER Geonuclear Corporation and the AEC.
May 17, 1973	Project Rio Blanco - A joint government-industry gas stimulation experiment. Participants - CER Geonuclear Corporation, the Atomic Energy Commission, the Department of the Interior. Technical Director - Lawrence Livermore Laboratory. Yield - 3, 30-kt explosives detonated simultaneously for an aggregate of 90 kt. Depth of Burial - 3 explosives spaced from 5800 to 6700 ft. underground. Medium - Sandstone, gas bearing formation. Chimney Dimensions - Predicted to produce a region of rubble and fractured rock approximately 350 ft in diameter and 1400 ft. in height. Site - Rio Blanco County, Colorado. About 50 miles due north of Grand Junction, Colorado. Objective - To test the feasibility of using vertically spaced multiple explosives in a single well bore to fracture a thick section of gas bearing sands.

Date	Event or Study
Proposed	Project Wagon Wheel - A joint government-industry gas stimulation experiment.

Participants - El Paso Natural Gas Company, the Atomic Energy Commission, the Department of the Interior.

Technical Director - Lawrence Livermore Laboratory.

Yield - 5, 100-kt explosives detonated sequentially.
Depth of Burial - The explosives will be buried from 9000 to 12,000 feet beneath the surface.
Medium - Sandstone, gas bearing formation.
Chimney Dimensions - The explosion will result in a volume of rubble and fractured rock not more than 440 ft. in diameter and less than 2800 ft. high at an average depth of about 10,000 ft.
Site - The northeastern part of the Green River Basin in Sublette County, Wyoming, about 20 miles south of the town of Pinedale.
Objectives - To test the feasibility of single hole, sequentially fired multiple explosives for stimulation of a large vertical section of a low permeability gas reservoir.

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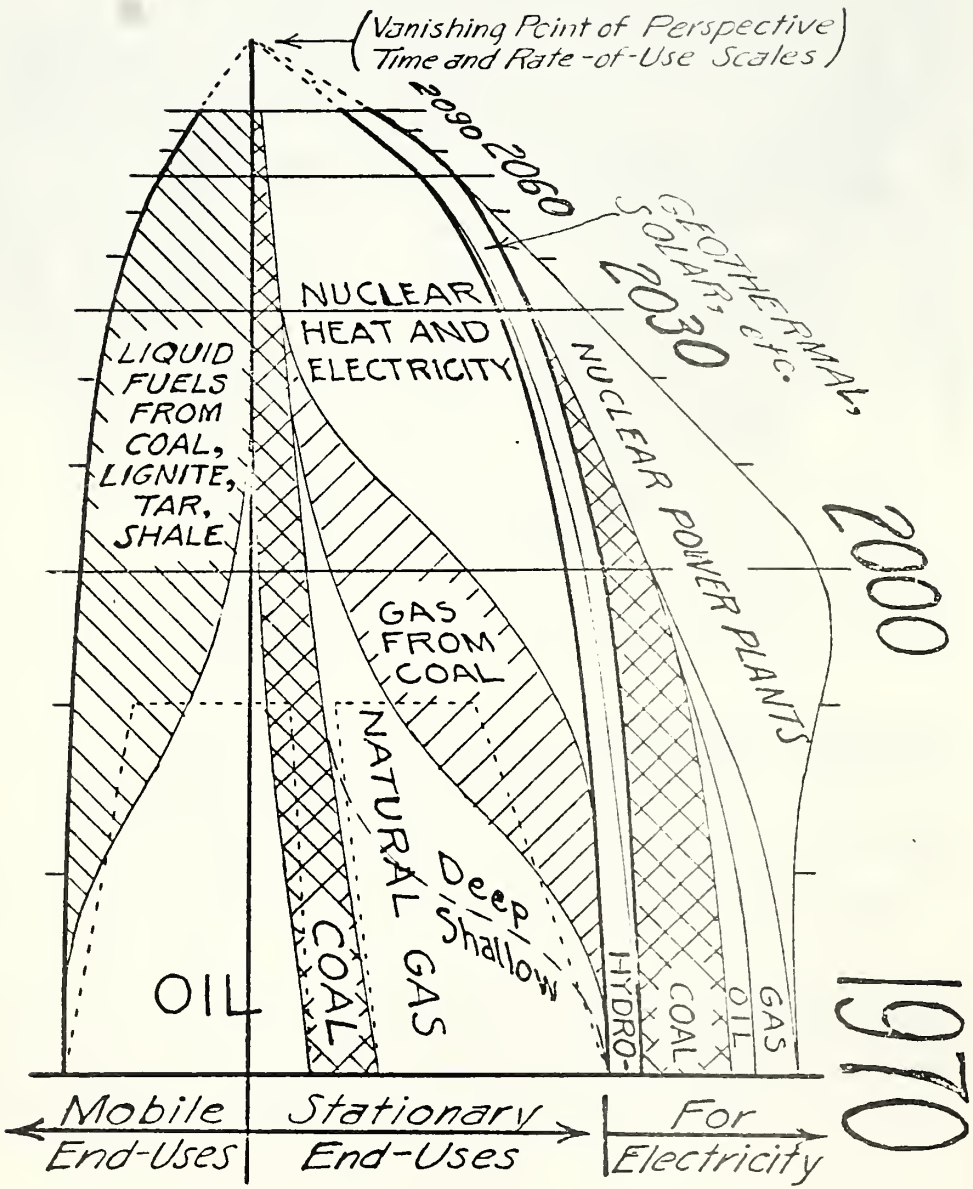
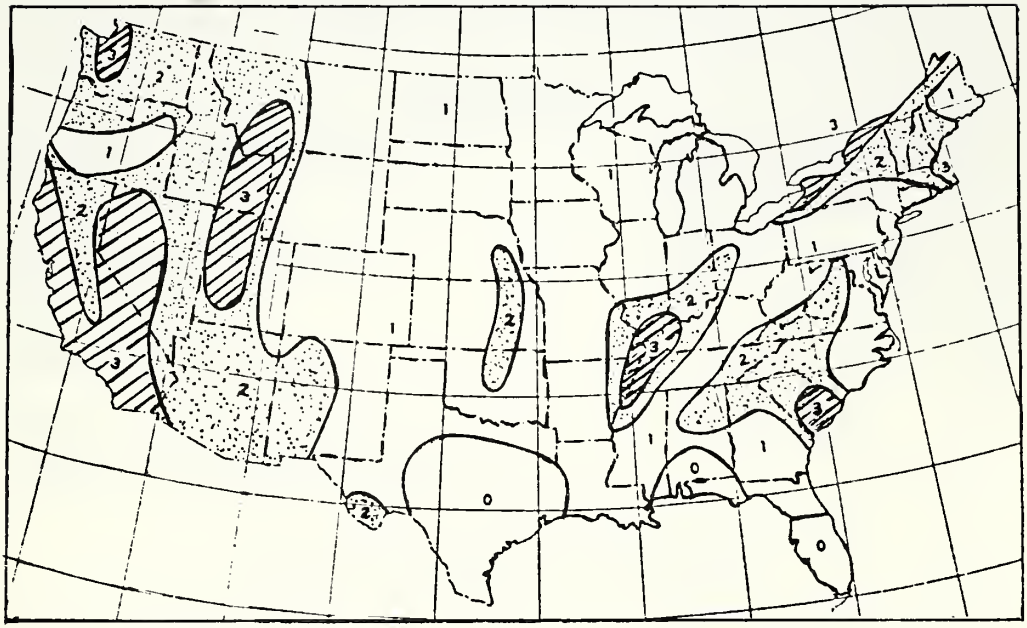


POSTULATED RATES OF USE
OF U.S. ENERGY RESOURCES

APPENDIX C

SEISMIC ZONE MAP OF THE UNITED STATES



Zone 0 - No damage.

Zone 1 - Minor damage: distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds; corresponds to intensities V and VI of the M.M.* Scale.

Zone 2 - Moderate damage: corresponds to intensity VII of the M.M.* Scale.

Zone 3 - Major damage: corresponds to intensity VIII and higher of the M.M.* Scale

This map is based on the known distribution of damaging earthquakes and the M.M.* intensities associated with these earthquakes; evidence of strain release; and consideration of major geologic structures and provinces believed to be associated with earthquake activity. The probable frequency of occurrence of damaging earthquakes in each zone was not considered in assigning ratings to the various zones.

*Modified Mercalli Intensity Scale of 1931.

Source: UNIFORM BUILDING CODE, 1970 Edition, Volume 1
International Conference of Building Officials
50 South Los Robles
Pasadena, California 91101

APPENDIX D

CER GEONUCLEAR CORPORATION MEETINGS
AND CONTACTS IN COLORADO

Public Meetings

Denver Area - Open Forum Sponsored by Colorado Open Space Council (COSC)	February 22, April 13, May 13, June 21, and October 7, 1971
Piceance Creek (Rock School), Meeker and Rangely	January 11, 12, and 13, 1971
De Beque, Piceance Creek (Rock School) and Meeker	January 17, 18, and 19, 1972
Denver Area - Public Meeting sponsored by ROMCOE (Governor's Special Advisory Committee attended)	February 3, 1972

Governor's Special Advisory Committee

Denver, Colorado	June 22, 1971
Grand Junction, Colorado	July 27-28, 1971
Las Vegas, Nevada	December 13-14, 1971
Meeker, Colorado (public meeting sponsored by Rio Blanco County Planning Commission)	January 19, 1972
West Auditorium of Denver Museum of Natural History (public meeting by ROMCOE)	February 3, 1972

State Agencies

Colorado Department of Natural Resources, State of Colorado	January 8, February 16, March 16, April 12, August 16, and September 22, 1971
Colorado Oil and Gas Commission	September 22, 1971
Governor's Office	April 13, 1971

(State Agencies, continued)

Lieutenant Governor's Office	September 23, 1971
Colorado Public Health Service	March 16 and September 23, 1971
State Legislators	August 16, 1971 and January 21, 1972
State Highway Department	September 23, 1971
Colorado Game, Fish and Parks Commission	August 26, 1970 and April 5, 1971
Colorado Water Conservation Board	
Western Interstate Nuclear Board	Continuous (Frank Young of CER)
Colorado Geological Survey, State of Colorado	February, August 16, and September 22, 1971
State Coordinator of Environmental Problems (Denver)	February 16, 1971
Colorado Land Use Commission (Denver)	

Federal Agencies

U.S. Geological Survey, Special Projects	August 16 and September 22, 1971
Environmental Protection Agency (Denver)	September 22, 1971
AEC Office of Compliance	September 22, 1971
Bureau of Land Management	August 25, 1970 and June 16 and September 23, 1971
U.S. Department of Agriculture Soil Conservation Service	
U. S. Bureau of Mines	February 16, 1971

Regional, County, and City Agencies

Rio Blanco Planning Commission	May 18, 1971 and February 15, 1972
Douglas Creek Soil Conservation District	
County Sheriffs (Mesa, Garfield, Rio Blanco)	April 5, 1971
Local (Rio Blanco County)	May 18 and August 7, 1971
Western Colorado Regional Planning Commission	December 28, 1971
Oil Shale Regional Planning Commission	December 28, 1971, and February 20, 1972
Yellow Jacket Water Conservancy District (Board of Directors, individually)	December 29, 1971
Rio Blanco Historical Society	January 13, 1971, and February 16, 1972

Industry

Grand Junction Chamber of Commerce (Dale Hollingsworth, Manager)	August 7, 1971
Oil Shale Interests	September and October, 1971
Colorado Interstate Gas	
Public Service Company of Colorado	August 16, 1971
Western Slope Gas	
Paraho Dev. Corporation	June 4, 1971
CONOCO	August 16, 1971
Union Carbide	
Rocky Mountain Gas	

Environmental Groups

Colorado Open Space Council (COSC)	February 22, April 13, May 13, June 21, and October 7, 1971
Rocky Mountain Center on Environment (ROMCOE)	February 22, March 16, August 16, and September 23, 1971, and February 3, 1972
Thorne Ecological Institute (TEI)	August 16, 1971
Audobon Society	February 16, 1971

Universities

Colorado State University, Extension Service	January 8, February 16, March 16, April 1, August 7, and August 16, 1971
University of Colorado	

Additional Meetings

During the six weeks just prior to the Rio Blanco detonation, 25 to 30 meetings were held in the nearby towns of Meeker, Rifle, Rangely, Grand Valley and DeBeque aimed at keeping the local communities completely informed.

APPENDIX E

STEPS IN AN INDUSTRIAL PLOWSHARE PROJECT*

1. Preliminary Studies of Potential Site and Surrounding Area
(Several months to several years)

Field work may begin when a project is hardly more than an idea. It may start with a trip to the area to look over the potential site, to get an idea of the relationship of the site to geographical and man-made features in the area, and to determine whether at the outset there is any circumstance or factor that might make a project at that particular potential site infeasible.

Other visits to the area will be necessary later by the industrial sponsor's personnel and by contractor personnel in gathering data for preliminary studies. During this period, residents of the area may be contacted about water wells, dairy herds, wildlife, water reservoirs including farm ponds, and other cultural and environmental aspects of the area. During this period also, long-term investigations of weather conditions, farming and ranching practices, naturally occurring (background) radiation, the environment, and other matters may be launched. At this stage, when a potential site is being evaluated, investigations are carried out by individuals or small groups of persons, and only a relatively few local residents may be contacted.

2. Detailed Geological, Chemical and Biological Investigations
(Several months to several years)

If the preliminary investigation leads to a conclusion that the site is probably satisfactory, more intensive study is undertaken. One or more holes may be drilled at the site to gather data about the geology underground and about groundwater, about the chemical composition of the rock in which the explosive would be emplaced, and about the composition and characteristics of the earth from the surface down to and beyond the probable explosive emplacement point.

During this stage, which may stretch over a period of several months to a year or more, many more residents of the area will be contacted and many will be asked to assist in some of the investigations. A variety of monitoring stations will be set up on strategic locations in the area. A program of periodic sampling of plant, animal, fish water, soil, air and milk samples will be undertaken. Information will be gathered on the number of people in the area and where they live, and on the general economic and social characteristics of the area. Milk cows and other livestock will be located and counted. Surveys of plant life will be launched. Wildlife in the area will be surveyed and its pattern of living recorded. Water wells will be located and examined.

*Source: Arnett, Joseph T., Industry and Nuclear Explosives, Atomic Industrial Forum, Inc., July 1973.

3. Formal Proposal by Industrial Sponsor

If these more detailed investigations of a possible site indicate that a project is feasible and that the site is suitable, the industrial sponsor may then make a formal proposal to the federal government that the project go forward.

4. AEC Review and Examination, Including Environmental Statement
(Several months)

The AEC will then review the project as proposed by the industrial sponsor and will conduct any additional investigations the government deems necessary to develop an acceptable project definition plan. This particular stage could cover a month or several months.

5. Site Preparation
(Several months)

If the government agrees to conduct a joint project, the next stage would involve site preparation. During this site preparation stage, which extends over a period of several months, a number of activities take place, such as preparation of the emplacement hole to receive the explosive and erection of necessary surface structures.

6. Emplacement of Explosive and Detonation
(Days to weeks)

Activities come to a peak with the emplacement of the explosive and its subsequent detonation.

7. Re-entry and Construction of Surface Facilities
(Several months to several years)

Following detonation, the tempo of activities drops off. In the case of a nuclear gas stimulation project, the major post detonation work centers on drilling of the re-entry hole. After the re-entry hole is completed and samples are taken, a few people may be involved in production testing for several months. For other types of industrial Plowshare projects several months to several years may be required for construction of the necessary surface facilities.

8. Facility Operation
(Several months to decades)

As with any industrial venture, the operation of the production facility will usually continue for a number of years in order to recover the initial investment.